THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE PERMANENT SECRETARY OF THE GEOLOGICAL SOCIETY.

Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant.
—*Novum Organum*, *Præfatio*.

VOLUME THE SEVENTY-SEVENTH,

FOR 1921.

LONDON:
LONGMANS, GREEN, AND CO.
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SOLD ALSO AT THE APARTMENTS OF THE SOCIETY.
MCMXXI.

List

OF THE

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Elected February 18th, 1921.

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Col. H. G. Lyons.
Dr. G. T. Prior.
Prof. S. H. Reynolds.
Prof. A. C. Seward.
Sir Aubrey Strahan.
Prof. W. W. Watts.

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No. 305—May 13th, 1921.
No. 306—August 19th, 1921.
No. 307—November 11th, 1921.
No. 308—December 31st, 1921.

PROCESS-BLOCKS AND OTHER ILLUSTRATIVE FIGURES

BESIDES THOSE IN THE PLATES.

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[With Two Plates, illustrating Papers by Mr. H. Bolton and Mr. D. Davies.]

MAY 13th, 1921.

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ORDINARY MEETINGS OF THE GEOLOGICAL SOCIETY TO BE HELD AT BURLINGTON HOUSE.

SESSION 1920–1921.

1921.

Wednesday, May 25*
,, June .... 8 —22*

[*Business will commence at 5.30 p.m. precisely.*]

The asterisks denote the dates on which the Council will meet.

PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1920-21.

November 3rd, 1920.

Mr. R. D. Oldham, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The President gave notice that a Special General Meeting would be held on Wednesday, December 1st, 1920, at 5.15 P.M., at which the following resolutions would be submitted to the Fellows:—

(1) That the Council be authorized to realize an amount not exceeding £500 from the invested funds of the Society.

(2) That the Council be authorized to exceed the annual income to the extent of the amount of securities thus sold, by treating the same as income for the purpose of the scientific publications of the Society.

The President then said:—

'In explanation of this notice, I may remind the Society that, when the conditions introduced by the recent war led to a temporary arrest of the scientific publications, the cessation of expenditure resulting from this enabled the Council to subscribe for £500 of the National Loan which was being raised in 1917. This money has always been regarded by the Council as standing on a different footing from the other permanent investments of the Society, and it has looked forward to the time when the funds, which were placed at the disposal of the nation in a time of national emergency, would be required for the purpose of overtaking arrears of publication. This time has now arrived: the clearing-up of arrears is in active progress, and the Council expects to be able in its next report to the Society to announce that all arrears of the Quarterly Journal have been cleared off As this will necessitate an expenditure in excess of that sanctioned by the Society at the last Annual General Meeting, the Council is asking for the

authority which will be necessary to satisfy the Auditors, and at the same time for power to realize, if necessary, from the permanent investments of the Society such an amount as may be necessary to meet the expenditure, and, as the procedure most advantageous to the Society may not be the sale of the actual investment made in 1917, they ask for a general power of realizing an equivalent amount, accompanied by a specific restriction of the purpose to which the sums realized may be applied.'

The following communication was read :—

'The Arctic Flora of the Cam Valley, at Barnwell, Cambridge.' By Miss Marjorie Elizabeth Jane Chandler. (Communicated by Prof. J. E. Marr, Sc.D., F.R.S., V.P.G.S.)

Specimens and microscope-sections were exhibited in illustration of Miss Chandler's paper.

November 17th, 1920.

Mr. R. D. Oldham, F.R.S., President,
in the Chair.

Daniel James Davies, B.Sc., F.C.S., Government Analyst for Newfoundland, St. John's (Newfoundland); Joseph Richard Harrison, Bokaro, *via* Adra, B.N.R. (India); John Prowett Le Grand, Assoc.M.Inst.C.E., 29 Mount Park Crescent, Ealing, W.5; Ganesh Govinda Narke, M.Sc., Poona, Bombay (India); Richard Payne, Mining Department, Education Office, Chesterfield (Derbyshire); Agustin Rosas, B.Sc., Peru 958, Mendoza (Argentine Republic); Frederick John Somerville, 2 King Street, Liverpool; and Darashaw Nowsherwan Wadia, M.A., B.Sc., Professor of Geology, Prince of Wales College, Jammu, Kashmir (India), were elected Fellows of the Society.

The List of Donations to the Library was read.

The appointment of Mr. N. E. Pettitt as Temporary Assistant was announced.

The following communications were read :—

1. 'A Seasonal Variation in the Frequency of Earthquakes.' (Second Communication.) By Richard Dixon Oldham, F.R.S., Pres.G.S.

2. 'Ecology of Plants from the Westphalian and the Lower Part of the Staffordian Series of Clydach Vale and Gilfach Goch (East Glamorgan).' By David Davies, F.G.S.

Rocks from the extinct volcano of Dereiba, Jebel Marra, and from other localities in Darfur, collected by Capt. Hubert Lynes, C.B., C.M.G., R.N., were exhibited by W. Campbell Smith, M.C., M.A., F.G.S.

Gold-bearing quartz from Post Office Hill, Ballarat, collected in 1853 (some of the earliest quartz-reef specimens worked in Victoria); a polished paper-weight of rich auriferous quartz from the shoot now being worked at Constellation Mine, Bendigo; and a diamond-crystal (about 2 carats), a perfect hexoctahedron, from Cock's Pioneer Mine, Eldorado, Victoria (deep alluvial), were exhibited by Prof. E. W. Skeats, D.Sc., F.G.S.

December 1st, 1920.

Mr. R. D. Oldham, F.R.S., President, in the Chair.

Lancaster Demorest Burling, 53 Parliament Street, Westminster, S.W. 1; Basil George Chilcott, Ashmore, St. Martin's (Guernsey); Ira Edmund Cornwall, Dominion Quarantine Station, William Head, Victoria (B.C.); Henry George Dacres Dixon, 8 Wilton Crescent, S.W. 1; Vincent Glenday, M.A., 15 Adam Street, Portman Square, W. 1; Rollo Hillyard Stafford Haydon, The Gables, Helston (Cornwall); Albert Heard, B.Sc., Woodstock, St. James's Road, Blackburn; the Rev. George Stewart Hitchcock, D.D., Greenfields, Frindsbury, Rochester (Kent); Wilfred Edgar Howarth, Assistant in the Geological Department of the National Museum of Wales, 53 Angus Street, Cardiff; Otway Henry Little, M.A., Geological Survey of Egypt, Dawawin P.O., Cairo (Egypt); Charles Isaac Littlehales, The Firs, Oswestry; Francis Turquand Mansfield, A.R.S.M., Dalmeny, 16 Barclay Road, East Croydon (Surrey); James Reid Moir, One House, Ipswich; (Miss) Lucy Ormrod, B.A., 36 Commercial Street, Newport (Monmouthshire); James Elliot Pillar, 1 Barn Park Road, Plymouth; Samuel Raymond Prisk, 46 Godolphin Road, Helston (Cornwall); Joseph Robert Ritson, B.A., 10 Hilda Place, Saltburn-by-the-Sea (Yorkshire); Malhari Vinayak Rao, Assistant Superintendent, Geological Survey of India, 27 Chowringhee Road, Calcutta; Sivaran Sethurama Rau, Assistant Superintendent, Geological Survey of India, 27 Chowringhee Road, Calcutta; Assan Sadek, B.Sc., Inspector, Geological Survey of Egypt, Dawawin P.O., Cairo (Egypt); Horatio Adlington Sandford, B.A., Briars Court, Gravesend (Kent); and Henry Cherry Versey, M.Sc., 14 Regent Terrace, Hyde Park, Leeds, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'An Æolian Pleistocene Deposit at Clevedon (Somerset).' By Edward Greenly, D.Sc., F.G.S.[1]

Specimens and microscope-slides were exhibited in illustration of Dr. Greenly's paper; and a dreikanter from Barnwood, Gloucester, was exhibited by C. I. Gardiner, M.A., F.G.S.

A Special General Meeting was held at 5.15 p.m. (before the Ordinary Meeting), in order to consider the resolutions already announced (see p. i).

After a brief discussion the resolutions were agreed to unanimously.

December 15th, 1920.

Mr. R. D. Oldham, F.R.S., President, in the Chair.

Alexander David Neil Bain, 13 Denmark Street, Gateshead; Walter Hellyer Bennett, 41 Southbrook Road, Lee, S.E. 12; Frank Young Henderson, 16 Dunearn Street, Glasgow, W.; Herbert Price Lewis, B.A., Oundle School (Northamptonshire); Eugene Florian Oliphant Murray, Asanboni, Singhbhum (India); Winfred Laurence Falkiner Nuttall, B.A., Longfield, Madingley Road, Cambridge; Colin Raeburn, B.Sc., Woodside Place, Larkhall (Lanarkshire); and Harold William Turner, B.A., Lecturer in Geology in the University of Bristol, 14 Lansdown Place, Clifton, Bristol, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Structure and Stratigraphy of the Tertiary Deposits in North-Western Peru.' By Thomas Owen Bosworth, D.Sc., M.A., F.G.S.

2. 'Palæontology of the Tertiary Deposits in North-Western Peru.' By Henry Woods, M.A., F.R.S., T. Wayland Vaughan, Ph.D., J. A. Cushman, Ph.D., and Prof. Herbert Leader Hawkins, D.Sc., F.G.S.

3. 'Geology of the Quaternary Period on a Part of the Pacific Coast of Peru.' By Thomas Owen Bosworth, D.Sc., M.A., F.G.S.

Rock-specimens, fossils, photographs, lantern-slides, and maps were exhibited in illustration of Dr. T. O. Bosworth's papers.

[1] Withdrawn by special request of the Author, with the view of relieving the pressure on the Quarterly Journal.

January 5th, 1921.

Mr. R. D. OLDHAM, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following Fellows of the Society, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year:—JOHN FREDERICK NORMAN GREEN, B.A., and SAMUEL HAZZLEDINE WARREN.

The following communications were read:—

1. 'The Lithological Succession of the Carboniferous Limestone (Avonian) in the Avon Section at Clifton, Bristol.' By Prof. Sidney Hugh Reynolds, M.A., Sc.D., F.G.S.

2. 'The Carboniferous Limestone of the Wickwar–Chipping Sodbury Area (Gloucestershire).' By Miss Edith Bolton, M.Sc., and Miss M. C. Tuck, B.Sc. (Communicated by Principal T. Franklin Sibly, D.Sc., F.G.S.)

Specimens, diagrams, and lantern-slides were exhibited in illustration of the paper by Prof. S. H. Reynolds and of that by Miss Bolton & Miss Tuck.

Compound flints from Teynham (Kent) were exhibited by Cecil Carus-Wilson, F.R.S.E., F.G.S.

Dreikanter and sun-sliced stones from the Desert of Tumbes (Peru) were exhibited by Dr. T. O. Bosworth, M.A., F.G.S.

January 19th, 1921.

Mr. R. D. OLDHAM, F.R.S., President,
in the Chair.

Stanley James Davies, The Ryelands, Colney Hatch Lane, New Southgate, N. 11; and Thomas Robertson, B.Sc., 26 D, Clanricarde Gardens, W. 2, were elected Fellows of the Society.

Dr. Frank Wigglesworth Clarke, Washington (D.C.), U.S.A.; Prof. Émile Haug, University of Paris; Prof. Maurice Lugeon, University of Lausanne (Switzerland); Prof. Hans Schardt, University of Zürich (Switzerland); Dr. Jakob Johannes Sederholm, Director of the Geological Survey of Finland, Helsingfors; and Dr. Henry Stephen Washington, Geophysical Laboratory, Washington (D.C.), U.S.A., were elected Foreign Members of the Society.

Prof. Lucien Cayeux, Collège de France, Paris; Dr. Maurice Cossmann, Paris; Prof. Henry de Dorlodot, University of Louvain (Belgium); Dr. Henri Douvillé, École Nationale Supérieure des Mines, Paris; Prof. Louis Duparc, University of Geneva (Switzerland); Prof. Johan Kiær, University of Christiania (Norway); Prof. Waldemar Lindgren, Massachusetts Institute of Technology, Boston (Mass.), U.S.A.; and Prof. John J. Stevenson, New York City, U.S.A., were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'The Lower Palæozoic Rocks of the Llangollen District, with especial reference to the Tectonics.' By Leonard Johnston Wills, M.A., Ph.D., F.G.S., and Bernard Smith, M.A., F.G.S.

Lantern-slides, etc. were exhibited in illustration of the paper by Dr. Wills & Mr. Smith.

February 2nd, 1921.

Mr. R. D. Oldham, F.R.S., President, in the Chair.

James Brown, 31 Balgreen Road, Edinburgh; Albert John Charles, B.Sc., Wynne Road, Blaenau Ffestiniog (North Wales); Henry George Dines, Assoc.R.S.M., Assoc.M.Inst.C.E., Longwood, Hurst Road, Bexley (Kent); John Samuel Duncan, B.Sc., c/o C. E. Duncan, 11/1 Coral Road, Entally, Calcutta (India); Herbert Edward Johnson, B.Sc., 16 Holland Park, W. 11; Edgar Alfred Merrett, B.Sc., 44 Roxborough Road, Harrow (Middlesex); Lewis F. Mizzi, LL.D., 33 Strada Mezzodì, Valletta (Malta); and Howard L. Sikes, B.A., B.E., Public Works Department, Nairobi (Kenya Colony), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'A New Species of Blattoid (*Archimylacris*) from the Keele Group (Radstockian) of Shropshire.' By Herbert Bolton, M.Sc., F.R.S.E., F.G.S.

2. 'The Granite-Gneisses of Southern Eyre Peninsula (South Australia) and their Associated Amphibolites.' By Cecil Edgar Tilley, B.Sc., A.I.C. (Communicated by Dr. H. H. Thomas, M.A., Sec.G.S.)

Specimens and lantern-slides were exhibited in illustration of the papers by Mr. H. Bolton and Mr. C. E. Tilley.

ANNUAL GENERAL MEETING.

February 18th, 1921.

Richard Dixon Oldham, F.R.S., President,
in the Chair.

Report of the Council for 1920.

During the year under review, 80 new Fellows were elected into the Society (1 less than in 1919). Of the Fellows elected in 1920, 50 paid their Admission Fees before the end of that year, and of the Fellows who had been elected in the previous year, 15 paid their Admission Fees in 1920, making the total accession of new Fellows during the past year amount to 65 (6 less than in 1919).

Allowing for the loss of 47 Fellows (12 resigned, 33 deceased, and 2 removed), but adding 4 Fellows re-instated, it will be seen that there is an increase of 22 in the number of Fellows (as compared with an increase of 15 in 1919).

The total number of Fellows is, therefore, at present 1229, made up as follows:—Compounders 207 (1 less than in 1919); Contributing Fellows 1012 (26 more than in 1919); and Non-Contributing Fellows 10 (3 less than in 1919).

Turning now to the Lists of Foreign Members and Foreign Correspondents, the Council announces with regret the decease during the past year of Prof. J. P. Iddings and Prof. Sven L. Törnquist, Foreign Members, and of Prof. A. von Kœnen, Foreign Correspondent. These losses increase the number of vacancies in the List of Foreign Members to eight, and in that of Foreign Correspondents to thirteen, at December 31st, 1920. One Foreign Correspondent has since resigned; while six Foreign Members (Dr. F. W. Clarke, Prof. E. Haug, Prof. M. Lugeon, Prof. H. Schardt, Dr. J. J. Sederholm, and Dr. H. S. Washington) and eight Foreign Correspondents (Prof. L. Cayeux, Dr. M. Cossmann, Prof. H. de Dorlodot, Dr. H. Douvillé, Prof. L. Duparc, Prof. J. Kiær, Prof. W. Lindgren, and Prof. J. J. Stevenson) have been elected. There still remain, therefore, two vacancies in the List of Foreign Members, and twelve vacancies in the List of Foreign Correspondents.

On February 4th, 1920, the following Fellows were nominated by the Council to serve on a Joint Committee on Petrological Nomenclature, in conjunction with members of the Mineralogical Society: Dr. J. V. Elsden, Dr. J. S. Flett, Sir Jethro Teall, Dr. H. H. Thomas, Mr. G. W. Tyrrell, and Prof. W. W. Watts. The Report formulated by this Committee will shortly be distributed to the Fellows.

With regard to the Income and Expenditure of the Society during 1920, the figures set forth in detail in the Balance-Sheet may be summarized as follows:—The actual Receipts (excluding the Balance of £376 13*s.* 8*d.* brought forward from the previous

year) amounted to £3675 9*s.* 10*d.* On the other hand, the Expenditure during the same year amounted to £4142 11*s.* 3*d.*, the deficiency being met by the transfer of £400 from the Balance of the Sorby & Hudleston Funds to the General Purposes Account.

At the beginning of the past year it was impossible to form any real estimate of several of the heads of expenditure; the estimates submitted were, therefore, purely formal, and no useful purpose would be served by comparison with the actual expenditure. To some extent the same difficulty of framing real estimates still exists, but it is anticipated that those now submitted for 1921 will prove substantially correct. They are presented in a form which differentiates between the normal income and expenditure of the year and the special expenditure arising from the arrears of publication which accumulated during the past five years.

On December 1st, 1920, the Council obtained authority from a Special General Meeting to realize the sum of £500 from the invested funds of the Society, being approximately the amount which it was able to invest in 1917, owing to the interruption of expenditure on publications. It has not been necessary as yet to exercise this authority; but, as the money may be required in the course of the current year, this sum has been put on the Estimates as extraordinary income.

During the past year the Council has given considerable and careful attention to the condition of the Society's finances, and was regretfully driven to the conclusion that it would be necessary to call on the Fellows for some further contribution in order to establish a condition of equilibrium. After reviewing all possible alternatives, it appeared to be best to confine the free issue of scientific publications to the Abstracts of Proceedings, and to supply the Quarterly Journal and List of Geological Literature only to those Fellows who were willing to make a payment, estimated at approximately equivalent to the actual cost of distribution, as apart from the fixed charges of publication.

As a further consequence of these deliberations, the cost of the List of Fellows, being an administrative and not a scientific publication, is now charged to Office expenses, but a more important change in the form of the Estimates is in the institution of a special fund for the maintenance of the Society's Apartments, from which all payments on account of decoration and repair of the Apartments and Furniture will be made. The institution of this separate fund was due to the Council's appreciation of the necessity, which will be forced on it in a very few years' time, of meeting an expenditure on redecoration very largely in excess of that which could be met out of annual income, and of the fact that such expenditure will be a liability recurring at intervals in the future.

In arriving at these conclusions, the Council was assisted, and largely guided, by the recommendations of a Committee, appointed by them, consisting principally of Fellows who were not members of the Council, but had special qualifications in matters of administration and finance. It was also assisted by two memoranda

prepared by the Officers for its information, dealing with the questions of general finance and of the publications of the Society. Believing that these memoranda will be of interest and utility to the Fellows, as a review of the present state of the Society's affairs and an indication of the difficulties of the position with which it had to contend, the Council has decided to present them to the Society as an appendix to the Annual Report.

During the year 1920 the four parts of the Quarterly Journal constituting Vol. LXXV were published, as also two parts of Vol. LXXVI. A third part was published on January 17th, 1921, and the fourth part will be issued shortly, thus clearing off the arrears of publication of the Quarterly Journal. No issue has been made of the List of Geological Literature, but the compilation has been resumed as from the commencement of 1920; the work has been carried on concurrently with the receipt of publications, and the List is in preparation for issue. The work of overcoming the arrears of the List for the years 1914–19 has been taken in hand, and is in progress.

During the past year the Apartments of the Society have been used for General and for Council Meetings by the Institution of Mining Engineers, the Institution of Mining & Metallurgy, the Institution of Water Engineers, the Society of Engineers, the Mineralogical Society, the Palæontographical Society, the Ray Society, the Royal Anthropological Institute & the Prehistoric Society of East Anglia, the Conjoint Board of Scientific Societies, and the South-Eastern Union of Scientific Societies.

Sir Aubrey Strahan and Prof. W. G. Fearnsides have continued to act during the year as the Geological Society's representatives on the Conjoint Board of Scientific Societies.

The Proceeds of the Prestwich and Barlow-Jameson Funds have been devoted to the preparation of the List of Geological Literature.

The Proceeds of the Daniel-Pidgeon Fund for 1919 and 1920 were awarded to Miss Marjorie Elizabeth Jane Chandler, who proposes to investigate the Oligocene Flora of the Hordle Cliffs (Hampshire), and to Mr. Laurence Dudley Stamp, who proposes to make a comparative study of the Downtonian and Gedinnian in North-Western Europe.

Further, the following Awards of Medals and Funds have been made:—

The Wollaston Medal is awarded in duplicate to Dr. John Horne and Dr. Benjamin Neeve Peach, in recognition of their conjoint and individual researches concerning the Mineral Structure of the Earth, especially in connexion with the tectonics, stratigraphy, and palæontology of the rocks of Scotland.

The Murchison Medal, together with a sum of Ten Guineas from the Murchison Geological Fund, is awarded to Mr. Edgar Sterling Cobbold, as an acknowledgment of the value of his stratigraphical and palæontological researches, more particularly on the fauna and succession of the Lower Cambrian rocks of Britain.

The Lyell Medal, together with a sum of Twenty-Five Pounds, is awarded to M. Emmanuel de Margerie, in recognition of his devotion to geological science and services to geology.

The Bigsby Medal is awarded to Dr. Lewis Leigh Fermor, in recognition of the value of his petrographical and mineralogical researches, more particularly in the region of British India.

The Balance of the Proceeds of the Wollaston Fund is awarded to Dr. Thomas Owen Bosworth, in recognition of the value of his geological work carried out both in this country and in South America, and to encourage him in further research.

The Balance of the Proceeds of the Murchison Fund is awarded to Dr. Albert Gilligan, as an acknowledgment of the value of his contributions to the geology and petrography of the Carboniferous rocks of England, and to stimulate him to further work.

A Moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Dr. Herbert Leader Hawkins, in recognition of the value of his palæontological researches, more particularly of his studies on the morphology and evolution of the Echinoidea, and to encourage him in further research.

A Moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. Cyril Edward Nowill Bromehead, as an acknowledgment of the value of his geological work, more especially on the geology of the Tertiary and Quaternary deposits of the London Basin, and to encourage him in further research.

Appendix.

Memorandum on the Finances of the Society. (Presented to the Council, March 24th, 1920.)

I. Review of the Past.

(1) The activities of the Society may be grouped under five headings:—

1. Upkeep of apartments.
2. Administration.
3. Maintenance of Library
4. Scientific publications.
5. Holding of periodical meetings.

A further form of activity is that of grants in aid of geological research and investigation: of this the Society has not been neglectful, but the expenditure, being mostly provided for by special funds and benefactions, does not appear, except in trivial amount, in the ordinary accounts.

Of the five headings above, the last three constitute the essential work of the Society, that for which it exists; the first two are necessary, but ancillary to the others. On this ground a strict accountancy should regard them as overhead charges, to be distributed over the other headings in order to ascertain the actual cost of each branch of the real work of the Society. It would be

difficult to decide the proportion in which such distribution should be made, and it will be more convenient to keep them apart as separate main headings, bearing in mind that any expenditure on Nos. 1 & 2 is only justifiable in so far as it is essential or contributory to carrying out the other three. When this is done, No. 5, the periodical meetings, disappears from the account, as it involves no special expenditure not covered by Nos. 1 & 2.

(2) The annual accounts of the Society are arranged for convenience of accountancy, but need some adjustment if the expenditure is to be classified by the different forms of its activities. Each of these four is specifically represented in the accounts, but under Publications are included certain charges which are more properly assignable to one of the other headings, and the whole cost of the staff is entered under the headings of Salaries, wages, &c. For the most part these salaries are easily assignable to their proper headings: that of the Permanent (formerly Assistant) Secretary belongs in greater or less degree to all, and as an approximate, and not wholly inequitable, apportionment we have assigned one-half to publications and one-sixth to each of the three other headings.

For the purpose of comparison we have taken the year 1919, the last for which complete accounts are available, 1914 as the last approximately normal year, and the two years 1909 and 1904; we have thus four years separated by intervals of five years which will give a very fair indication of the general conditions during the last twenty years. For each of these, the actual total ordinary expenditure in even pounds sterling, classified by the different headings of activity as in (1), is as follows:—

	1904.	1909.	1914.	1919.
Apartments	457	664	713	643
Administration	490	444	494	587
Library	529	531	480	536
Scientific Publications	1242	1466	1235	1482
Other	60	—	100	11
Totals	£2778	3105	3022	3259

In 1914 the Society's Apartments were redecorated and altered, the opportunity was taken to overhaul and renew the furniture, hence higher expenditure under this heading; the 'other' expenditure represents a pension then being paid. For purposes of comparison it will be more convenient to have these figures in the form of percentages of total ordinary expenditure. These are as follows:—

	1904.	1909.	1914.	1919.
Apartments	16	21	24	20
Administration	18	14	16	18
Library	19	18	16	17
Scientific Publications	45	47	41	45
Other	2	0	3	0

From this it will be seen that before 1914 the Library and Publications between them absorbed 64 and 65 per cent. of the total expenditure, or close on two-thirds, leaving about one-third for the other two ancillary activities; this may be regarded as a thoroughly satisfactory proportion between the two groups. In 1914 the percentage had fallen to 57, but the year was somewhat abnormal, the expenditure on apartments was unusually large, and before the end of the year the dislocation of the staff, consequent on the war, had already begun to affect the out-turn of scientific publications. In 1919 the percentage had risen to 62, which may be regarded as not unsatisfactory from the accountancy point of view, the primary functions absorbing three-fifths and the ancillary two-fifths of the total expenditure.

(3) Before proceeding, it will be useful to see how this classification of expenditure by different forms of activity compares with the headings adopted in the Annual Accounts, which are given below, with the sole modification that the separate headings of Library and Library Catalogue are combined. As before, only ordinary expenditure is taken into consideration:—

	1904.	1909.	1914.	1919.
House expenditure	238	444	452	353
Salaries, wages, etc.	887	871	1072	1247
Office expenditure	149	165	164	191
Library and Catalogue	207	339	233	123
Publications	1237	1306	1099	1334
Other expenditure	60	—	—	11
Totals...........	£2778	3125	3020	3259

Expressed as percentages these figures become:—

	1904.	1909.	1914.	1919.
House expenditure	9	14	15	11
Salaries, wages, etc.	32	28	35	38
Office expenditure	6	5	6	6
Library and Catalogue	7	11	8	4
Publications	44	42	36	41
Other expenditure...........	2	0	0	0

Stated in this form, Library and Publications accounted for 51 and 53 per cent. in the first two years, and 44 and 45 per cent. in the last two. It would seem from this that the existing form of account can give a very fair criterion of whether the proportion between the expenditure on essential and that on ancillary activity is satisfactory, and that so long as the headings of expenditure on Library and Publications account for half of the total, the allocation of expenditure may be regarded as satisfactory. At present the proportion is less than the half, but not very seriously so, if we consider merely the expenditure in pounds sterling; but if we regard the out-turn of work done, the aspect is very different. At present costs, the same expenditure on publications represents

less than half the pre-war out-turn of printed matter, and this means a reduction by a half of the time required for editorial work in the Society's offices; the same Library expenditure similarly represents a reduction in work done, though not to the same extent. With an increasing expenditure on staff there has been a material diminution in out-turn of work, and the necessity has arisen of revising not merely the scale of remuneration, but the number and duties of our staff.

II. Review of Present Conditions.

(4) In reviewing the present financial condition some reference needs to be made to the Society's invested funds, which stand at a book value of £14,191; were the realizable value anything like this the amount would be ample, but at present values the investments would not realize more than about £7750; of this, too, £475 stands on a different footing from the rest, as it represents money which, having accumulated at the credit of the Society, was placed at the disposal of the Nation in a time of national emergency, but this had only accumulated through the practical suspension of publication owing to the war, and should in equity be reserved for bringing up arrears of publication. Deducting this, the actual realizable value of the invested funds is little over £7000, or not much more than two years' income. For the security of the Society this fund should be raised to the realizable value of not less than three years' income and, as there is no present prospect of doing this, it is essential to avoid anything which might lead to a necessity for trenching on the present inadequate reserve.

(5) Before proceeding, it will be useful to consider what income would be necessary to enable the Society to carry on just as before the war, to publish the same amount of matter and to maintain all its then activities on the same scale. This we find to amount to from £5200 to £5300, an all-round average increase of about 75 per cent. on the pre-war expenditure of about £3,000. The income from all ordinary sources amounted last year to £3432, but this is in excess of the normal ordinary income, as more than one cause cooperated in giving an unusually large accession of Fellows; it is probable that these causes have not ceased to be effective, and that the income of £3542, estimated for the present year, may be reached, but this level is not likely to be permanently maintained, and the actual average income from all sources is, in existing conditions, between £3200 and £3300. This income has the satisfactory quality of being to some degree elastic, as the increased contributions received from newly-elected Fellows will lead to each year being on the average about £50 better than the preceding one, but it is at present quite £2000 short of that needed to maintain pre-war activities.

(6) As the only possible source of immediate material increase in the income is raising the subscription of Fellows elected previously to the present Session, it is necessary to estimate the probable increase which would result if this course were followed. The total number of Fellows on January 1st was 1203, of whom 208 have compounded and cannot be touched; there were also 81 non-contributing Fellows from whom no subscription can be expected. This leaves 982 contributing Fellows, some of whom already pay at the rate of three guineas; there are consequently, in round numbers, some 950 who might be affected. An increase of a guinea in the subscription would not, however, produce an income of 950 guineas, for though a Special General Meeting might make it impossible for any one to retain his Fellowship, if he did not pay the increased subscription, it could not prevent him from resigning, or allowing his Fellowship to lapse, if he was unwilling or unable to pay. The general experience is that any change in subscription leads to a loss of about 20 per cent. of the membership, and, if our case is so far special that the percentage would not be so high, we must reckon on a certain loss of at least 100 and a probable loss of 150.

Taking the last-mentioned figure, an increase from 2 to 3 guineas would mean a loss of 300 and a gain of 800 guineas, or a net gain of £525 on the present income, an amount which is but a small fraction of that needed. If the increase were to 4 guineas the resignations would probably not be materially different, but the net increase of income would be raised to some £1300. An annual contribution of 5 guineas would produce the income needed to maintain our pre-war activity, if there were no material increase in the number of resignations, of which it is impossible to form an estimate. A proposal of this character would indubitably lead to a great upheaval in the Society, its consequences are incalculable, and the risks too great for it to be considered in the present circumstances.

(7) The only possible means of raising the income to the level required for maintaining the old standard of activity being impracticable, it is necessary to see whether it is not possible, by a readjustment of expenditure and establishment, to carry on the Society's activities, though in a less degree than formerly, without change in the existing rates of contribution.

In examining this possibility it will be convenient to take each major heading of the Annual Accounts separately.

House Expenditure. Most of the sub-heads are not susceptible of material modification. On the two sub-headings Furniture & Repairs, and House Repairs & Maintenance, the actual expenditure in 1919 was £99 in all; this we consider inadequate as a regular standard of expenditure. The Society's Apartments are convenient and commodious, but needed a higher expenditure than this for their maintenance before the War: they were put in thorough order in 1914 by the expenditure of £694 on redecoration

and £239 on furniture, and this has enabled the Society to carry on with a reduced expenditure on maintenance and repairs; but the influence of the work done in 1914 is wearing off, and we are of opinion that an average of £150 per annum at least should be devoted to this purpose, apart from the necessity of providing for larger work of redecoration in the future, and that any reduction below this figure will not be an economy but merely a postponement of expenditure, probably enhanced by delay. This increase would make the ordinary total of this heading £400 in round figures.

Salaries and Wages. Under this heading we have examined the question of the staff necessary to carry on the work of the Society. Bearing in mind that with an unaltered income the bulk of publications issued must be largely reduced from the pre-war standard, we have, after consultation with the Permanent Secretary, come to the conclusion that it could, for the present, be carried on by three persons. If the recommendations of the Officers are adopted, the total of all charges included in this heading of account would amount to about £1200.

Office Expenditure amounted in 1919 to £190, it is not susceptible of material decrease, nor is it likely to rise to any great extent. The total may be taken as about £200.

Library and Library Catalogue we propose to take together. The actual expenditure in 1919 was £123, the estimate for 1920 is £185: both these figures we consider to be inadequate as permanent provision. The Society is possessed of an extensive and valuable library of geological literature, and with regard to this there are only two courses worthy of consideration: one is to maintain the existing standard of the Library, the other is to give it up, as the Society did its museum, retaining only a small consulting library of more frequently required books. The latter course would lead to a gross saving, under all heads of account, of about £500 per annum, but we are convinced that any suggestion of this character would encounter the most strenuous disapprobation of the Fellows of the Society. The alternative remains of efficient maintenance of the Library, and for this we regard the allocation, for the two headings of account, of £250 as not more than sufficient.

Publications. The allotments detailed above would leave £1250 for this heading, out of an income of £3300.

On this basis the headings of Library, Catalogue, and Publications would account for 45 per cent. of the total expenditure, but with a permanent increase of the total income to £3500 the allotment for publications could be increased and the three headings account for nearly 49 per cent. of the expenditure; with a further increase of income to £3700 the percentage would rise to 51, but with this increase in the bulk of publications the staff proposed would probably prove inadequate, and the increase under this heading would reduce the percentage available for expenditure on Library and Publications.

(8) From this statement of the case it appears that the Society will be able to carry on its activities, and to maintain an approximation to the proportion of expenditure on essential and ancillary purposes which we have adopted as the ideal to be aimed at, if the condition is accepted that the actual bulk of matter which the Society is able to publish must be reduced to somewhat less than half of what it was able to issue previous to 1914. A further proviso must be made that the possibility is entirely dependent on the devotion and willingness of the permanent staff in assisting the Society to tide over a critical period, and that it may be necessary to abandon or diminish some minor activities which, however desirable in themselves, would interfere with others of greater importance. We are, therefore, of opinion that no sufficient case has been made out for the immediate submission to the Society of a proposal for modification in the contributions of its Fellows, and that it is preferable to wait until it is seen whether the amount of original matter offered for, and worthy of, publication is so far in excess of that which it will be possible to publish as to justify the proposal.

(9) No provision has been made for arrears of publication in the allotment of expenditure detailed above. These we believe can be provided for by the sum now invested, which we have mentioned as equitably applicable to this purpose, and by the balances at credit of the Sorby and Hudleston bequests, which could be diverted to this purpose, if necessary, from that for which it had been intended to use them.

(10) In the course of their investigation of the Society's finances, the Officers' attention has been given to two points in the form of the Annual Accounts.

The first is the inclusion of the List of Fellows under the heading of Publications. As this is not a scientific publication, but an incident of the administration of the Society, the cost seems more appropriate to the heading of Office Expenditure.

The second is the treatment of sums received as Composition and Entrance Fees. The reasons of accountancy which justify the treatment of regularly recurring receipts as part of the ordinary income are fully recognized, but these reasons carry with them the correlative obligation to make provision, on the other side of the account, for possible unforeseen expenses, as well as for those which recur at longer intervals and in larger amounts than can be provided for out of a single year's income. We think that it would be easier for an unfinancial body to understand the position, if a proportion of the Composition and Entrance Fees were automatically carried to a reserve fund, from which expenditure of the character just referred to could be met, and that part of the reserve fund so established should be held in some more liquid form than the permanent investments which now constitute the only reserve at the disposal of the Society.

Memorandum on the Publications of the Society. (Presented to the Council, June 23rd, 1920.)

(1) In the Memorandum on the Finances of the Society it was shown that, according to the general scheme of finance, now accepted by the Council, there would be a sum of about £1250 available for scientific publications, after meeting other necessary charges. Of this the Abstracts of Proceedings will absorb about £200, the regular issue of the List of Geological Literature about £250, leaving £800 available for the Quarterly Journal, or about the sum actually spent per volume in the last few years; during which only a small number of papers were offered for publication.

The return to more normal conditions has made a change in this respect, a larger number of original contributions has been submitted to the Society, and the Publication Committee have passed, as worthy of publication in the Quarterly Journal, an amount of matter which was estimated to cost nearly £1700, and, with costs of printing and paper now higher than at the time when some of the estimates were prepared, the actual cost will be not less and probably higher than the estimate. The sum required is, consequently, rather more than double of what can be provided out of actual income, if the present series of publications and standard of merit is preserved.

(2) It must be noted that the increase in the cost of papers passed for publication does not indicate any undue leniency on the part of the Publication Committee, nor any unusual glut of papers due to passing causes. Before 1914 the ordinary cost of the Journal varied between about £800 and £1000 per annum, and for this the Society was able to publish all the matter offered which it regarded as worthy of publication. With the increased cost of paper, printing, and especially of illustrations, the expenditure previous to 1914 would now be equivalent to from £2000 to £2500 per annum, and the £1700 passed by the Publication Committee during the present Session may be regarded as an approximate return to normal conditions, and not as a passing phase.

(3) Something might be done towards balancing expenditure with income by bringing pressure on authors to condense their communications; some of the more questionably suitable papers might be eliminated, but the reduction which could so be made would go a very short way towards covering the deficit, and there are only three courses open. First, to set a much higher standard for publication, and to reject more than half of what is now considered fit; secondly, to restrict the distribution of the Journal, and abandon one or both of the other forms of publication; or thirdly, to find a fresh source of income.

The first of these is fraught with difficulty and danger; were the reduction merely a matter of 10 or 20 per cent. it might be feasible, but when the reduction amounts to fully 60 per cent., it ceases to be so. From the papers submitted and at present passed for publication it would be impossible to separate out one half as distinctly more valuable than the rest, and the elimination of one half would certainly exclude from publication much which is of unmistakable interest and value. This method of solving the problem seems to be inconsistent with the object of the Society's existence, and in the end detrimental to its interests.

The second course would at best but partly meet the difficulty. The Council has already decided that the Abstracts of Proceedings shall be continued, it will probably be averse to discontinuing the List of Geological Literature, and, even if both were abandoned, only about £450 would be provided, or not more than half of the sum required to maintain the Quarterly Journal with the existing standard of fitness for publication. Another possible source of saving which suggests itself and has been carefully investigated, is a restriction on the distribution of the Journal; at present it is distributed free to every Fellow (with the exception of 13 who have specially asked that it shall not be sent), and, if the distribution were restricted to those who took the trouble to ask specially for it, there would be a saving through the smaller number which need be printed. The amount of this saving is difficult to estimate exactly, but it would be between £10 and £15 per 100 copies on each number costing about £250 to produce, that being about the cost of the more recent numbers of the Journal. It is also impossible to gauge the reduction which could be made in the numbers printed; but it would need that more than half the Fellows should forego their Journal to give a saving of £450 per annum, and it is certain that not nearly this proportion would be willing to do so, more especially if the issue of the Abstracts of Proceedings were abandoned.

There remains, then, the third solution, an increase of income, and one way of procuring this would be an all-round increase of the rate of Annual Contribution. This source of income has been fully investigated and discussed in the Memorandum on the Finances of the Society, where it was shown that a general increase to 3 guineas a year would not produce as much as is needed, and an increase to 4 guineas should yield more than is required. The other arguments against this procedure remaining as cogent as ever, its adoption cannot be recommended until other methods have been tried and found wanting.

(4) One such method would be the cessation of the free distribution of the Journal to all Fellows. That some regular periodical publication should be so distributed seems essential to the welfare and even the continuance of the Society; but, for this purpose, the comparatively inexpensive Abstracts of Proceedings would

serve as well as the more costly Quarterly Journal, and, if the Abstracts of Proceedings were issued free, most of the objections to making a charge for the Journal would be met. The additional cost of distributing the Abstracts of Proceedings to all Fellows would be about £20 per annum at present rates and costs; the saving on every copy of the Journal not printed and distributed is from 2*s.* to 2*s.* 6*d.* according to the size of the number. Taking this as a basis, if a charge of 10 shillings a year were made, it would produce an income in cash or equivalent savings of round about £600 a year, whatever might be the number of Fellows taking or not taking the Journal, and this sum, though not quite as much as would be desirable, would enable the publication of at least three-quarters of the papers presented to the Society, and regarded as worthy of publication, apart from questions of cost.

In many ways, this course seems to have arguments in its favour. It would need no alteration in the constitution or Bye Laws, such as an increase of subscription would involve, for the privileges of Fellows do not extend to the free receipt of publications, but only to purchase at a reduced cost. The charge proposed would not be likely to prevent any Fellow who wished to possess, and had use for, the whole issue of the Journal from being able to obtain it, while it would prevent some hundreds of copies of an expensive production from becoming waste paper, and restrict the issue to the number really required; at the same time, those Fellows who only needed those numbers containing papers in which they are specially interested would be kept informed of the publications through the medium of the Abstracts of Proceedings, and could obtain the particular numbers which they wished for at a special reduced rate. A further and very important point in favour of this method of procuring an increased income is its elasticity; a change in the general rate of contribution involves the summoning of a Special General Meeting and an alteration of the Bye Laws, a change in the charge for publications is within the powers and functions of the Council, so that with the normal growth of income of the Society, which may be expected, it will be possible to reduce gradually the charge until the desirable condition of a free issue of all publications is resumed.

As it is essential to the carrying out of this scheme that the number of copies of the Journal required for distribution should be known beforehand, the charge should be leviable strictly in advance, and Fellows advised to remit it together with their subscriptions; and, as a demand for occasional copies introduces an element of uncertainty in the number of copies required, a charge of say 3*s.* should be made if applied for within a year of publication, after which the regular rate of 5*s.* a copy would become payable.

(5) The Quarterly Journal having been dealt with, it is necessary to consider the List of Geological Literature. The last number published is that for the year 1912. The number for 1913 is in

a forward state, we are committed to the publication of this, and it should be ready for issue soon. The current additions to the Library are being dealt with as they come in, the work is being kept up to date by the Librarian and the manuscript of the 1920 List should be ready for the press early in 1921. The publication it is hoped will be ready for issue by the middle of that year, and should be issued in any case before the end. As in the case of the Journal, the saving in cost, due to restriction of the number printed, will be dependent on knowledge of the number required for issue. This may be obtained in part by asking for prepayment from Fellows requiring the issue regularly, the demand for the Journal will also give grounds for an estimate of the probable requirements, and, as the cost of publication will be about the same as an average number of the Journal, the rate of charge might be fixed, as to amount and conditions, on the same basis as that for a single number of the Journal.

(6) A decision on this point cannot, however, be reached without also considering the arrears of the six years 1914–19 inclusive. If these are to be cleared off with celerity it will be necessary to employ outside assistance, and the fees payable cannot be reckoned at less than £500 for the preparation of manuscript and correction of proofs. The work might perhaps be carried out by members of our permanent staff, but in that case would have to be done out of regular office hours; in this case, too, special remuneration would have to be paid (on a lower scale, seeing that no account need be taken of the out-of-pocket cost and loss of time involved in special visits to the Library, and that account should be taken of the indirect advantages of the familiarity with the arrangements of the Library arising from regular connexion with it), the time necessary for the completion of the work would be largely extended, and arrears could not be cleared off in less than five or six years, probably longer. In addition to the cost of compilation and correction, the cost of publication would have to be met, and this cannot be put at less than £1200. From this it will be seen that for clearing off the arrears of the List of Geological Literature provision will have to be made for a sum of at least £1500, and possibly as much as £2000. There appear, therefore, to be only two courses open, either to bring this issue to a close with the 1913 number, or to resume issue as from 1920, leaving the arrears to be cleared off as funds become available. The arguments both for and against either of these courses seem weighty and about evenly balanced; but it may be pointed out that, while the latter is financially feasible if the proposals set forth in this memorandum are adopted, it will not be so if they are rejected, unless some other source of additional income is provided.

Report of the Library Committee for 1920.

The Donations received during the year 1920 number 48 Volumes of separately published Works, 344 Pamphlets, and 8 detached Parts of Works, also 200 Volumes and 326 detached Parts of Serial Publications, 82 Volumes and 632 Parts of the publications of Geological Surveys and other public bodies, and 17 Volumes of Weekly Periodicals.

39 sheets of Geological Maps were received during the year.

The number of accessions by Donation amounts, therefore, to 347 Volumes, 344 Pamphlets, and 966 detached Parts.

Special attention may be drawn to the following works :—

'Recherches Géologiques & Pétrographiques sur le District Minier de Nicolaï-Pavda,' by L. Duparc & A. Grosset, text & atlas, 1916 ; 'Resumo da Geologia do Brasil para acompanhar o Mappa Geologico do Brasil,' by J. C. Branner, 1919 ; 'An Introduction to the Study of Fossils,' by H. L. Hawkins, 1920; 'Oil-Finding,' by E. H. Cunningham-Craig, 2nd Edition, 1920 ; 'Allgemeine Paläontologie, Geologische Fragen in Biologischer Betrachtung,' Parts I & II, by J. Walther, 1919 ; Egypt, Petroleum-Research Bulletins 2, 3, 4, 5, 7, & 8—'Geological Reports on Oilfields in Egypt & Sinai,' by W. F. Hume & others, 1920 ; Smithsonian Institution, Bulletin 106—'North American Early Tertiary Bryozoa,' by F. Canu & R. S. Bassler, 1920 ; 'Japanische Triasfaunen,' by Carl Diener, 1915 ; 'Expédition de la Célèbès Centrale—Voyages Géologiques & Géographiques à travers la Célèbès Centrale' (1909–1910), by E. C. Abendanon & others, 3 volumes & atlas, 1916–1918 ; Memoirs of the Geological Survey of Great Britain, Special Reports on the Mineral Resources of Great Britain, vii—Mineral Oil, Kimmeridge Oil-Shale, Lignites, Jets & Cannel Coals, Natural Gas, England & Wales, by Sir Aubrey Strahan & others, 1920 ; xi—'Iron-Ores of Scotland,' by M. MacGregor & others, 1920 ; xv—'Arsenic & Antimony-Ores,' by H. Dewey & others, 1920 ; xvi—'Sand for Open-Hearth Steel Furnaces—Dolomite, Petrography & Chemistry,' by H. H. Thomas & others, 1920 ; 'The Geology of Anglesey,' by E. Greenly, 2 volumes & map, 1919 ; and Memoirs of the Geological Survey of Scotland—'Mesozoic Rocks of Applecross, Raasay, & North-East Skye,' by G. W. Lee, 1920.

The Donors during the preceding year included 107 Government Departments and other Public Bodies, 118 Societies and Editors of Periodicals, and 91 Personal Donors.

During the year exchange of publications, suspended during the war, was resumed with several Societies, Government Departments, and other Institutions on the Continent which had expressed their desire to renew relations with this Society, and had sent the arrears of their Publications to our Library.

The Purchases included 21 Volumes and 23 detached Parts of Works, and 7 Volumes and 10 detached Parts of Works published serially.

The Expenditure incurred in connexion with the Library during 1920 was as follows:—

	£	s.	d.
Books and Periodicals	56	4	3
Binding	48	3	3
Sundries	3	1	0
Total	£107	8	6

The appended Lists contain the Names of Government Departments and other Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review:—

I. Government Departments and other Public Bodies.

Akita Mining College, Akita (Japan).
Alsace-Lorraine.—Service de la Carte Géologique. Strasbourg.
Alabama.—Geological Survey. Montgomery (Ala.).
American Museum of Natural History. New York.
Australia (S.), etc. *See* South Australia, *etc.*
Austria.—Geologische Reichsanstalt. Vienna.
Bavaria.—Bayerisches Oberbergamt. Munich.
Belgium.—Académie Royale des Sciences, des Lettres & Beaux-Arts de Belgique, Brussels.
——. Musée Royal d'Histoire Naturelle. Brussels.
Bergens Museum. Bergen.
Brazil.—Escola Superior de Agricultura & Medecina Veterinaria. Nictheroy.
——. Serviço Geologico & Mineralogico do Brasil. Rio de Janeiro.
Bristol.—Museum & Art Gallery.
Buenos Aires.—Museo Nacional de Buenos Aires.
California.—Academy of Sciences. San Francisco.
——, University of. Berkeley (Cal.).
Cambridge (Mass.).—American Academy of Arts & Sciences.
——. Museum of Comparative Zoology in Harvard College.
Canada.—Geological & Natural History Survey. Ottawa.
Cape of Good Hope.—South African Museum. Cape Town.
Chicago.—'Field' Columbian Museum.
Connecticut.—State Geological & Natural History Survey. Hartford (Conn.).
Córdoba (Argentine Republic).—Academía Nacional de Ciencias.
Denmark.—Geologiske Undersögelse. Copenhagen.
——. Kongelige Danske Videnskabernes Selskab. Copenhagen.
Dublin.—Royal Irish Academy.
Egypt.—Department of Public Works (Survey Department). Cairo.
Federated Malay States.—Government Geologist. Kuala Lumpur.
Finland.—Finlands Geologiska Undersökning. Helsingfors.
France.—Ministère de l'Instruction Publique. Paris.
——. Muséum d'Histoire Naturelle. Paris.
Gold Coast.—Geological Survey. Accra.
Great Britain.—Colonial Office. London.
——. Geological Survey. London.
——. Home Office. London.
——. Imperial Institute. London.
Hawaiian Observatory. Honolulu.

Holland.—Departement van Kolonien. The Hague.
Hungary.—Ungarische Geologische Anstalt (Magyar Földtani Tarsulat). Budapest.
Illinois.—Geological Survey. Urbana (Ill.).
India.—Geological Survey. Calcutta.
Indo-China, French.—Service Géologique. Hanoi-Haiphong.
Japan.—Earthquake-Investigation Committee. Tokio.
——. Geological Survey. Tokio.
Kentucky.—Geological Survey. Frankfort (Ky.).
La Plata, Museo de.
Liége.—Collège des Bourgmestres & Échevins.
Madrid.—Real Academía de Ciencias Exactas, Físicas & Naturales.
Maryland.—Geological Survey. Baltimore (Md.).
Mexico.—Instituto Geológico. Mexico City.
——. Secretaria de Industria, Comercio & Trabajo. Mexico City.
Milan.—Reale Istituto Lombardo di Scienze & Lettere.
Minnesota.—Geological Survey. St. Paul.
——. School of Mines. Minneapolis.
Missouri.—Bureau of Geology & Mines. Rolla (Mo.).
Munich.—Bayerische Akademie der Wissenschaften.
Mysore.—Geological Department. Bangalore.
Nancy.—Académie de Stanislas.
Naples.—Accademia delle Scienze.
New Jersey.—Geological Survey. Trentham (N.J.).
——. Department of Conservation. Trentham (N.J.).
New South Wales.—Department of Mines & Agriculture. Sydney.
New York State Museum. Albany (N.Y.).
New Zealand.—Board of Science & Art. Wellington.
——. Department of Mines. Wellington.
——. Geological Survey. Wellington.
Padua.—Regia Università.
Paris.—Académie des Sciences.
Peru.—Ministerio de Fomento. Lima.
Philippine Is.—Department of the Interior: Bureau of Science. Manila.
Pisa.—Regia Università.
Quebec.—Department of Colonization, Mines, & Fisheries. Quebec.
Queensland.—Department of Mines. Brisbane.
——. Geological Survey. Brisbane.
Rhodesian Museum. Bulawayo.
Rio de Janeiro.—Museu Nacional.
Rome.—Reale Accademia dei Lincei.
Rumania.—Academia Română. Bucarest.
Scotland.—Geological Survey. Edinburgh.
South Africa.—Department of Mines of the Cape of Good Hope.
South Australia, Agent-General for. London.
——. Department of Mines. Adelaide.
——. Geological Survey. Adelaide.
Southern Rhodesia.—Geological Survey. Salisbury.
Spain.—Instituto Geologico. Madrid.
St. Louis (Mo.).—Washington University.
Stockholm.—Kongliga Svenska Vetenskaps Akademi.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Switzerland.—Geologische Kommission der Schweiz. Berne.
Tasmania.—Secretary for Mines. Hobart.
——. Geological Survey. Hobart.
Tokio.—College of Science.
Travancore.—State Geologist. Madras.
Turin.—Reale Accademia delle Scienze.
United States.—Geological Survey. Washington (D.C.).
——. National Museum. Washington (D.C.).
——. National Research Council. Washington (D.C.).
Victoria (Australia), Agent-General for. London.
—— (——). Department of Mines. Melbourne.
—— (——). Geological Survey. Melbourne.
Vienna.—Naturhistorisches Hofmuseum.
Wales.—National Museum. Cardiff.

Washington (D.C.).—Smithsonian Institution.
——. Geophysical Laboratory.
West Indies.—Imperial Agricultural Department. Bridgetown (Barbados).
Western Australia.—Department of Mines. Perth.
——. Geological Survey. Perth.
Yale University Museum (Peabody Museum). Geological Department. New Haven (Conn.).

II. Societies and Editors.

Adelaide.—Royal Society of South Australia.
Basel.—Naturforschende Gesellschaft.
Belfast.—Natural History Society.
Bergen.—'Naturen.'
Berlin.—Deutsche Geologische Gesellschaft.
——. Institut für Meereskunde & Geographisches Institut.
Bombay Branch of the Royal Asiatic Society.
Bordeaux.—Société Linnéenne.
Boston (Mass.).—American Academy of Arts & Sciences.
Bristol Naturalists' Society.
Brussels.—Société Royale Zoologique & Malacologique de Belgique.
Budapest.—Földtani Közlöny.
Buenos Aires.—Sociedad Cientifica Argentina.
Caen.—Société Linnéenne de Normandie.
Calcutta.—Asiatic Society of Bengal.
Cambridge Philosophical Society.
Cape Town.—Royal Society of South Africa.
——. South African Association for the Advancement of Science.
Cardiff.—South Wales Institute of Engineers.
Cheltenham.—Natural Science Society.
Chicago.—'Journal of Geology.'
Christiania.—'Nyt Magazin for Naturvidenskaberne.'
Darmstadt.—Verein für Erdkunde.
Dorchester.—Dorset Natural History & Antiquarian Field-Club.
Dorpat.—Naturforschende Gesellschaft.
Dresden.—Naturwissenschaftliche Gesellschaft 'Isis.'
Dublin.—Irish Naturalist.
——. Royal Dublin Society.
Edinburgh.—Geological Society.
——. Royal Scottish Geographical Society.
——. Royal Society.
Falmouth.—Royal Cornwall Polytechnic Society.
Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.
Freiburg im Breisgau.—Naturforschende Gesellschaft.
Fribourg.—Société Fribourgeoise des Sciences Naturelles.
Geneva.—Société de Physique & d'Histoire Naturelle.
Glasgow.—Geological Society.
Gloucester.—Cotteswold Naturalists' Field-Club.
Halifax (N.S.).—Nova Scotian Institute of Science.
Helsingfors.—Société Finlandaise de Géographie.
Johannesburg.—Geological Society of South Africa.
Lancaster (Pa.).—'Economic Geology.'
Lausanne.—Société Vaudoise des Sciences Naturelles.
Liége.—Revue de Géologie.
——. Société Géologique de Belgique.
Liverpool Geological Society.
London.—'The Athenæum.'
——. British Association for the Advancement of Science.
——. Chemical Society.
——. 'The Chemical News.'
——. 'The Colliery Guardian.'
——. 'The Geological Magazine.'

London. Geologists' Association.
——. Institution of Civil Engineers.
——. Institution of Mining Engineers.
——. Institution of Mining & Metallurgy.
——. Iron & Steel Institute.
——. Linnean Society.
——. 'The London, Edinburgh, & Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'The Mining Magazine.'
——. 'Nature.'
——. 'The Naturalist.'
——. 'The Quarry.'
——. Ray Society.
——. Royal Agricultural Society.
——. Royal Astronomical Society.
——. Royal Geographical Society.
——. Royal Meteorological Society.
——. Royal Microscopical Society.
——. Royal Photographic Society.
——. Royal Society.
——. Royal Society of Arts.
——. Society of Engineers.
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.
Manchester.—Literary & Philosophical Society.
Manila.—'Philippine Journal of Science.'
Melbourne (Victoria).—Australasian Institute of Mining Engineers.
——. Royal Society of Victoria.
——. 'The Victorian Naturalist.'
Mexico.—Sociedad Científica 'Antonio Alzate.'
Newcastle-upon-Tyne.—North of England Institute of Mining & Mechanical Engineers.
——. University of Durham Philosophical Society.
New Haven (Conn.).—Academy of Arts & Sciences.
——. 'The American Journal of Science.'
New York.—Academy of Sciences.
——. American Institute of Mining Engineers.
Northampton.—Northamptonshire Natural History Society.
Ottawa.—Royal Society of Canada.
Palermo.—'Il Naturalista Siciliano.'
Paris.—Annales des Mines.
——. Annales Hydrographiques.
——. Notes Provençales.
——. Société Française de Minéralogie.
——. Société Géologique de France.
Perth.—Perthshire Society of Natural Sciences.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
Plymouth.—Devonshire Association for the Advancement of Science.
Rennes.—Société Scientifique & Médicale de l'Ouest.
Rochester (N.Y.).—Academy of Science.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
Santiago de Chile.—Sociedad Nacional de Minería.
Stockholm.—Geologiska Förening.
Stratford.—Essex Field-Club.
Sydney (N.S.W.).—Linnean Society of New South Wales.
——. Royal Society of New South Wales.
Toronto.—Royal Canadian Institute.
Torquay Natural History Society.
Upsala.—Geological Institution of the University.
Washington (D.C.).—Academy of Sciences.
——. Geological Society of America.
Wellington (N.Z.).—New Zealand Institute.
Whitby Literary & Philosophical Society.
York.—Yorkshire Philosophical Society.

III. Personal Donors.

Abendanon, E. C.
Agababian, G. J.

Baker, H. A.
Bell, A.
Berry, J.
Blumer, E.
Booth, W. H.
Boswell, P. G. H.
Bosworth, T. O.
Branner, J. C.
Brown, J. C.
Burls, H. T.

Carus-Wilson, C.
Chatley, H.
Craig, E. H. C.

Daly, R. A.
Davies, G. M.
Dehaut, E. G.
Diener, C.
Dollfus, G. F.
Douglas, J. A.
Duparc, L.
Du Toit, A. L.

Fearnsides, W. G.
Foshag, W. F.
Friedel, G.

Greenwood, H. W.
Gregory, J. W.

Hawkins, H. L.
Henderson, J.
Hickling, G.
Holmes, A.
Holtedahl, O.
Howorth, Sir Henry H.
Howchin, W.
Hutchinson, H. N.

Issel, A.

Jackson, J. W.
Jones, O. T.
Jones, T. A.
Julian, Mrs. H.

Kew, W. S. W.
Kirsopp, J.
Kitchin, F. L.

La Touche, T. H. D.
Leach, A. L.
Leith, C. K.
Lencewicz, S.
Louderback, G. D.

Maitland, A. G.
Margerie, E. de.
Meli, R.
Merrill, G. P.
Moir, J. R.
Montag, E.
Morgan, P. G.

Newton, R. B.
Nicolesco, C.
Nopcza, Baron F.

Osborn, H. F.

Parkinson, J.
Penzer, N. M.
Pringle, J.
Pruvost, P.

Reid, H. F.
Renier, A.
Reusch, H.
Richardson, W. A.
Roig, M. S.
Roxo, M. G. de O.

Sabot, R.
Sacco, F.
Saint-Jours, B.
Schardt, H.
Seward, A. C.
Shannon, E. V.
Sheppard, T.
Sherlock, R. L.
Skeats, E. W.
Smith, B.
Spencer, J. W.
Stigand, I. A.
Stillwell, F. L.

Taber, S.
Termier, P.
Törnquist, S. L.

Vogt, J. H. L.

Walther, J.
Whitaker, W.
Withers, T. H.
Woolacott, D.

Comparative Statement of the Number of the Society at the Close of the Years 1919 and 1920.

	Dec. 31st, 1919.		Dec. 31st, 1920.
Compounders	208	....	207
Contributing Fellows	986	....	1012
Non-Contributing Fellows	13	....	10
	1207		1229
Foreign Members	34	....	32
Foreign Correspondents	28	....	27
	1269		1288

Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the Years 1919 and 1920.

Number of Compounders, Contributing, and Non-Contributing Fellows, December 31st, 1919		1207
Add Fellows elected during the former year and paid in 1920		15
Add Fellows elected and paid in 1920		50
Add Fellows reinstated		4
		1276
Deduct Compounders deceased	5	
Contributing Fellows deceased	25	
Contributing Fellows resigned	12	
Non-Contributing Fellows deceased	3	
Fellows removed in accordance with Sect. VI, Art. 5, of the Bye-Laws	2	
	—	47
		1229
Number of Foreign Members and Foreign Correspondents, December 31st, 1919	62	
Deduct Foreign Members and Correspondents deceased	3	
	59	
	—	59
		1288

DECEASED FELLOWS.

Compounders (5).

Cardiff, R. [elected in 1909].
Cliff, D. Y. [el. 1889].
Gayner, C. [el. 1865].
Jobling, M. E. [el. 1882].
Tackhadakar, M. A. [el. 1869].

Contributing Fellows (25).

Armstrong, J. A. H. [elected in 1909].
Baxter, W. E. [el. 1879].
Bell, A. M. [el. 1899].
Bennett, F. J. [el. 1875].
Black, J. M. [el. 1875].
Codd, J. A. [el. 1919].
Davies, H. N. [el. 1889].
Fergie, G. [el. 1872].
Gerrard, J. [el. 1907].
Hind, W. [el. 1891].
Home, D. R. [el. 1906].
Lapworth, C. [el. 1872].
Linck, F. W. [el. 1911].
Randell, Rev. T. [el. 1885].
Sopwith, A. [el. 1867].
Sweet, G. [el. 1890].
Thomson, A. G. M. [el. 1901].
Udall, J. [el. 1887].
Ussher, W. A. E. [el. 1868].
Wakelam, H. T. [el. 1910].
Watts, W. [el. 1878].
Wood, Major J. T. [el. 1886].
Young, A. P. [el. 1884].

Non-Contributing Fellows (3).

Bettington, A. [elected in 1845].
Clarke, J. [el. 1858].
Wathen, G. H. [el. 1855].

FELLOWS RESIGNED (12).

Brooks, C. E. P.
Carne, J. E.
Cooper, Sir Robert E.
Cornish, V.
Davison, C.
Dunn, S. C.
Mawson, J.
Nash, H. B.
Nuttall, H.
Stokes, H. G.
Tom, I.
Varah, A. C.

FELLOWS REMOVED (2).

Edwards, Rev. R. S.
Kirkcaldy, N. M.

FELLOWS ELECTED (65).

Acton, T. A.
Allison, F. W.
Bennett, W. H.
Berry, L. W.
Best, C. C.
Billington, H. C.
Brown, H. C. B.
Brown, W. A.
Buttle, D.
Campbell, J. M.
Carruthers, J. N.
Cave-Brown-Cave, N.
Challinor, J.
Chatwin, C. P.
Collinson, G. R.
Creber, W. F. H.
Davies, J.
Day, A. E.
Gardner, A. C.
George, B. C.
Heard, A.
Herbert, H. P.

Hitchcock, Rev. G. S.
Hodgson, B.
Howarth, W. E.
Hughes, E.
Jenkins, D. M.
Lane, W. T.
Langford, W. G.
Lewis, W. S.
Lomax, J.
Loxton, S. E.
Mansfield, F. T.
Marr, F. A.
Merrick, E.
Morgan, A.
Murchison, R. C.
Ormrod, Miss L.
Park, M.
Payne, R.
Petch, F.
Pitts, Miss F. A.
Pooley, H.
Pruvost, P.
Reid, Mrs. E. M.
Ricketts, H. W.
Ross, P.
Sale, H. M.
Sandford, H. A.
Searle, H. V.
Shakespear, Dame E. M. R.
Shannon, W. G. St. J.
Smith, R. H.
Somerville, F. J.
Spencer, E.
Starkey, T.
Turner, E. A.
Verney, H. C.
Wagner, P. A.
Walker, H. J.
Wells, A. K.
Wheaton, H. J.
White, F. W.
Wild, R. P.
Williams, G. W.

Foreign Members Deceased (2).

Iddings, J. P. [elected in 1904].
Törnquist, S. L. [el. 1900].

Foreign Correspondent Deceased.

Kœnen, A. von [elected in 1890].

After the Reports had been read, it was resolved :—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved :—

That the thanks of the Society be given to Dr. Herbert Lapworth, retiring from the office of Secretary and also from the Council; to Prof. J. E. Marr, retiring from the office of Vice-President and also from the Council; to Dr. J. V. Elsden, retiring from the office of Treasurer; and to the retiring Members of the Council: Mr. R. G. Carruthers, Dr. A. M. Davies, Mr. J. Allen Howe, and Prof. H. H. Swinnerton.

After the Balloting-Glasses had been closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year:—

OFFICERS AND COUNCIL.—1921.

PRESIDENT.

Richard Dixon Oldham, F.R.S.

VICE-PRESIDENTS.

Prof. Edmund Johnston Garwood, M.A., Sc.D., F.R.S.
George William Lamplugh, F.R.S.
Col. Henry George Lyons, D.Sc., F.R.S.
George Thurland Prior, M.A., D.Sc., F.R.S.

SECRETARIES.

Herbert Henry Thomas, M.A., Sc.D.
Walter Campbell Smith, M.C., M.A.

FOREIGN SECRETARY.

Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.

TREASURER.

Robert Stansfield Herries, M.A.

COUNCIL.

Francis Arthur Bather, M.A., D.Sc., F.R.S.
Prof. William S. Boulton, D.Sc., Assoc.R.C.Sc.
Thomas Crosbee Cantrill, B.Sc.
James Archibald Douglas, M.A., B.Sc.
James Vincent Elsden, D.Sc.
John Smith Flett, O.B.E., M.A., M.B., LL.D., D.Sc., F.R.S.
Prof. Edmund Johnston Garwood, M.A., Sc.D., F.R.S.
Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.
John Frederick Norman Green, B.A.
Robert Stansfield Herries, M.A.
Prof. Owen Thomas Jones, M.A., D.Sc.
Prof. Percy Fry Kendall, M.Sc.
William Bernard Robinson King, O.B.E., M.A.
George William Lamplugh, F.R.S.
Col. Henry George Lyons, D.Sc., F.R.S.
Lt.-Col. Sir Arthur Henry McMahon, K.C.I.E., C.S.I., G.C.V.O.
Richard Dixon Oldham, F.R.S.
George Thurland Prior, M.A., D.Sc., F.R.S.
Prof. Sidney Hugh Reynolds, M.A., Sc.D.
Walter Campbell Smith, M.C., M.A.
Sir Aubrey Strahan, K.B.E., Sc.D., LL.D., F.R.S.
Herbert Henry Thomas, M.A., Sc.D.
Prof. William Whitehead Watts, M.A., Sc.D., LL.D., F.R.S.

LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1920.

Date of Election.

1884. Commendatore Prof. Giovanni Capellini, *Bologna.*
1886. Prof. Gustav Tschermak, *Vienna.*
1891. Prof. Charles Barrois, *Lille.*
1893. Prof. Waldemar Christofer Brögger, *Christiania.*
1893. Prof. Alfred Gabriel Nathorst, *Stockholm.* (*Deceased.*)
1894. Prof. Edward Salisbury Dana, *New Haven, Conn.* (*U.S.A.*).
1896. Prof. Albert Heim, *Zürich.*
1897. Dr. Hans Reusch, *Christiania.*
1898. Dr. Charles Doolittle Walcott, *Washington, D.C.* (*U.S.A.*).
1899. Prof. Emanuel Kayser, *Munich.*
1899. M. Ernest Van den Broeck, *Brussels.*
1900. M. Gustave F. Dollfus, *Paris.*
1900. Prof. Paul von Groth, *Munich.*
1901. Dr. Alexander Petrovich Karpinsky, *Petrograd.*
1901. Prof. Antoine François Alfred Lacroix, *Paris.*
1903. Prof. Albrecht Penck, *Berlin.*
1903. Prof. Anton Koch, *Budapest.*
1904. Prof. Henry Fairfield Osborn, *New York* (*U.S.A.*).
1905. Prof. Louis Dollo, *Brussels.*
1907. Dr. Emil Ernst August Tietze, *Vienna.*
1907. Commendatore Prof. Arturo Issel, *Genoa.*
1908. Prof. Bundjirô Kôtô, *Tokyo.*
1909. Prof. Johan H. L. Vogt, *Trondhjem.*
1911. Prof. Baron Gerard Jakob De Geer, *Stockholm.*
1911. M. Emmanuel de Margerie, *Strasbourg.*
1912. Prof. Marcellin Boule, *Paris.*
1913. Prof. Johannes Walther, *Halle an der Saale.*
1914. Prof. Friedrich Johann Becke, *Vienna.*
1914. Prof. Thomas Chrowder Chamberlin, *Chicago, Ill.* (*U.S.A.*).
1914. Prof. Franz Julius Lœwinson-Lessing, *Petrograd.*
1914. Prof. Alexis Petrovich Pavlow, *Moscow.*
1914. Prof. William Berryman Scott, *Princeton, N.J.* (*U.S.A.*).

LIST OF

THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1920.

Date of Election.

1889. Dr. Rogier Diederik Marius Verbeek, *The Hague.*
1898. Dr. W. H. Dall, *Washington, D.C.* (*U.S.A.*).
1899. Dr. Gerhard Holm, *Stockholm.*
1899. Prof. Theodor Liebisch, *Berlin.*
1900. Prof. Federico Sacco, *Turin.*
1902. Dr. Thorvaldr Thoroddsen, *Copenhagen.*
1904. Dr. Erich Dagobert von Drygalski, *Charlottenburg.*
1904. Prof. Giuseppe de Lorenzo, *Naples.*
1904. The Hon. Frank Springer, *East Las Vegas, New Mexico* (*U.S.A.*).
1904. Dr. Henry Stephens Washington, *Washington, D.C.* (*U.S.A.*).
1906. Prof. John M. Clarke, *Albany, N.Y.* (*U.S.A.*).
1906. Prof. William Morris Davis, *Cambridge, Mass.* (*U.S.A.*).
1906. Dr. Jakob Johannes Sederholm, *Helsingfors.*
1908. Prof. Hans Schardt, *Zürich.*
1909. Dr. Daniel de Cortázar, *Madrid.*
1909. Prof. Maurice Lugeon, *Lausanne.*
1911. Prof. Arvid Gustaf Högbom, *Upsala.*
1911. Prof. Charles Depéret, *Lyons.*
1912. Dr. Frank Wigglesworth Clarke, *Washington, D.C.* (*U.S.A.*).
1912. Dr. Whitman Cross, *Washington, D.C.* (*U.S.A.*).
1912. Baron Ferencz Nopcsa, *Temesmegye* (*Hungary*).
1912. Prof. Karl Diener, *Vienna.*
1912. Prof. Fusakichi Omori, *Tokyo.*
1912. Prof. Ernst Weinschenk, *Munich.*
1913. Dr. Émile Haug, *Paris.*
1913. Dr. Per Johan Holmquist, *Stockholm.*

[NOTE.—The Lists of Awards of Medals and Funds, up to the year 1907 inclusive, are published in the 'History of the Geological Society.']

AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE 'DONATION FUND,'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

"To promote researches concerning the mineral structure of the Earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,'—'such individual not being a Member of the Council.'

1908. Prof. Paul von Groth.
1909. Mr. Horace B. Woodward.
1910. Prof. William B. Scott.
1911. Prof. Waldemar C. Brögger.
1912. Sir Lazarus Fletcher.
1913. The Rev. Osmond Fisher.
1914. Prof. John Edward Marr.
1915. Prof. T. W. Edgeworth David.
1916. Dr. A. P. Karpinsky.
1917. Prof. A. F. A. Lacroix.
1918. Dr. Charles D. Walcott.
1919. Sir Aubrey Strahan.
1920. Prof. G. J. De Geer.
1921. { Dr. B. N. Peach.
Dr. John Horne.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON 'DONATION FUND.'

1908. Dr. Herbert Henry Thomas.
1909. Mr. Arthur J. C. Molyneux.
1910. Mr. Edward B. Bailey.
1911. Prof. Owen Thomas Jones.
1912. Mr. Charles Irving Gardiner.
1913. Mr. William Wickham King.
1914. Mr. R. Bullen Newton.
1915. Mr. Charles Bertie Wedd.
1916. Mr. William Bourke Wright.
1917. Prof. Percy G. H. Boswell.
1918. Mr. Albert Ernest Kitson.
1919. Dr. A. L. Du Toit.
1920. Mr. William B. R. King.
1921. Dr. Thomas O. Bosworth.

AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, Bart., F.R.S., F.G.S.

'To be applied in every consecutive year, in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.'

1908. Prof. Albert Charles Seward.
1909. Prof. Grenville A. J. Cole.
1910. Prof. Arthur P. Coleman.
1911. Mr. Richard Hill Tiddeman.
1912. Prof. Louis Dollo.
1913. Mr. George Barrow.
1914. Mr. William A. E. Ussher.
1915. Prof. William W. Watts.
1916. Dr. Robert Kidston.
1917. Dr. George F. Matthew.
1918. Mr. Joseph Burr Tyrrell.
1919. Miss Gertrude L. Elles.
1920. Dame E. M. R. Shakespear.
1921. Mr. Edgar Sterling Cobbold.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE

'MURCHISON GEOLOGICAL FUND.'

1908. Miss Ethel Gertrude Skeat.
1909. Dr. James Vincent Elsden.
1910. Mr. John Walker Stather.
1911. Mr. Edgar Sterling Cobbold.
1912. Dr. Arthur Morley Davies.
1913. Mr. Ernest E. L. Dixon.
1914. Mr. Frederick Nairn Haward.
1915. Mr. David Cledlyn Evans.
1916. Mr. George Walter Tyrrell.
1917. Dr. William Mackie.
1918. Mr. Thomas Crook.
1919. Mrs. Eleanor Mary Reid.
1920. Dr. David Woolacott.
1921. Dr. Albert Gilligan.

AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS OF THE

'LYELL GEOLOGICAL FUND,

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, BART., F.R.S., F.G.S.

The Medal 'to be cast in bronze and to be given annually' (or from time to time) 'as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,'—'not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions, at the discretion of the Council, for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.'

There is a further provision for suspending the award for one year, and in such case for the awarding of a Medal to 'each of two persons who have been jointly engaged in the same exploration in the same country, or perhaps on allied subjects in different countries, the proportion of interest always not being less to each Medal than one third of the annual interest.'

1908. Mr. Richard Dixon Oldham.
1909. Prof. Percy Fry Kendall.
1910. Dr. Arthur Vaughan.
1911. { Dr. Francis Arthur Bather.
Dr. Arthur Walton Rowe. }
1912. Mr. Philip Lake.
1913. Mr. Sydney S. Buckman.
1914. Mr. Charles S. Middlemiss.
1915. Prof. Edmund J. Garwood.
1916. Dr. Charles W. Andrews.
1917. Dr. Wheelton Hind.
1918. Mr. Henry Woods.
1919. Dr. William Fraser Hume.
1920. Dr. Edward Greenly.
1921. M. E. de Margerie.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'LYELL GEOLOGICAL FUND.'

1908. Prof. T. Franklin Sibly.
1908. Mr. H. J. Osborne White.
1909. Mr. H. Brantwood Maufe.
1909. Mr. Robert G. Carruthers.
1910. Dr. F. R. Cowper Reed.
1910. Dr. Robert Broom.
1911. Prof. Charles Gilbert Cullis.
1912. Dr. Arthur R. Dwerryhouse.
1912. Mr. Robert Heron Rastall.
1913. Mr. Llewellyn Treacher.
1914. The Rev. Walter Howchin.
1914. Mr. John Postlethwaite.
1915. Mr. John Parkinson.
1915. Dr. Lewis Moysey.
1916. Mr. Martin A. C. Hinton.
1916. Mr. Alfred S. Kennard.
1917. Prof. A. Hubert Cox.
1917. Mr. Tressilian C. Nicholas.
1918. Mr. Vincent Charles Illing.
1918. Mr. William Kingdon Spencer.
1919. Mr. John Pringle.
1919. Dr. Stanley Smith.
1920. Dr. John D. Falconer.
1920. Mr. Ernest S. Pinfold.
1921. Dr. Herbert L. Hawkins.
1921. Mr. C. E. N. Bromehead.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially 'as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much.'

1909. Dr. John Smith Flett.
1911. Prof. Othenio Abel.
1913. Sir Thomas H. Holland.
1915. Dr. Henry Hubert Hayden.
1917. Mr. Robert G. Carruthers.
1919. Sir Douglas Mawson.
1921. Dr. Lewis L. Fermor.

AWARDS OF THE PRESTWICH MEDAL,

ESTABLISHED UNDER THE WILL OF THE LATE

SIR JOSEPH PRESTWICH, F.R.S., F.G.S.

'To apply the accumulated annual proceeds . . . at the end of every three years, in providing a Gold Medal of the value of Twenty Pounds, which, with the remainder of the proceeds, is to be awarded . . . to the person or persons, either male or female, and either resident in England or abroad, who shall have done well for the advancement of the science of Geology; or, from time to time to accumulate the annual proceeds for a period not exceeding six years, and apply the said accumulated annual proceeds to some object of special research bearing on Stratigraphical or Physical Geology, to be carried out by one single individual or by a Committee; or, failing these objects, to accumulate the annual proceeds for either three or six years, and devote such proceeds to such special purposes as may be decided.'

1909. Lady (John) Evans.
1912. Library extension.
1915. Prof. Émile Cartailhac.
1918. Sir William Boyd Dawkins.
1921. List of Geological Literature.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

Dr. H. C. BARLOW, F.G.S.

'The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1908. 'Grey-Wether' sarsens on Marlborough Downs.
1911. Mr. John Frederick Norman Green.
1913. Mr. Bernard Smith. Mr. John Brooke Scrivenor.
1915. Mr. Joseph G. Hamling.
1917. Mr. Henry Dewey.
1921. List of Geological Literature.

AWARDS OF THE PROCEEDS OF THE 'DANIEL-PIDGEON FUND,'

FOUNDED BY MRS. PIDGEON, IN ACCORDANCE WITH THE WILL OF THE LATE

DANIEL PIDGEON, F.G.S.

'An annual grant derivable from the interest on the Fund, to be used at the discretion of the Council, in whatever way may in their opinion best promote Geological Original Research, their Grantees being in all cases not more than twenty-eight years of age.'

1908. Mr. James A. Douglas.
1909. Dr. Alexander M. Finlayson.
1910. Mr. Robert Boyle.
1911. Mr. Tressilian C. Nicholas.
1912. Mr. Otway H. Little.
1913. Mr. Roderick U. Sayce.
1914. Prof. Percy G. H. Boswell.
1915. Mr. E. Talbot Paris.
1916. Dr. John K. Charlesworth.
1917. Dr. Arthur Holmes.
1918. Mr. James A. Butterfield.
1920. Miss M. E. J. Chandler.
1920. Mr. L. Dudley Stamp.

INCOME EXPECTED.

	£	s.	d.	£	s	d.
Compositions	105	0	0			
Admission-Fees, 1921	378	0	0			
				483	0	0
Arrears of Annual Contributions	150	0	0			
Annual Contributions, 1921	2000	0	0			
Annual Contributions in advance	90	0	0			
Quarterly Journal Subscriptions	200	0	0			
Record of Geol. Lit. Subscriptions	30	0	0			
				2470	0	0
Sale of the Quarterly Journal, including Longmans' Account				350	0	0
Sale of other Publications				15	0	0
Miscellaneous Receipts				30	0	0
Interest on Deposit-Account				20	0	0
Dividends on £2500 India 3 per cent. Stock	75	0	0			
Dividends on £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	15	0	0			
Dividends on £2250 London & North-Western Railway 4 per cent. Preference Stock	90	0	0			
Dividends on £2800 London & South-Western Railway 4 per cent. Consolidated Preference Stock	112	0	0			
Dividends on £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	51	16	0			
Dividends on £267 6*s.* 7*d.* Natal 3 per cent. Stock.	8	0	0			
Dividends on £500 5 per cent. War Stock (1929–1947)	25	0	0			
				376	16	0
Total Ordinary Income				£3744	16	0
Special Receipts.						
Realization of Invested Funds (authorized by the Special General Meeting held on December 1st, 1920)				500	0	0
Proceeds of the Barlow-Jameson and Prestwich Funds				122	18	3
Estimated Deficit				252	5	9
				£4620	0	0

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
Repairs and Maintenance Fund				250	0	0
House-Expenditure:						
Taxes & Fire-Insurance	25	0	0			
Electric Lighting and Maintenance	65	0	0			
Gas	40	0	0			
Fuel	60	0	0			
Annual Cleaning	25	0	0			
Washing and Sundry Expenses	70	0	0			
Tea at Meetings	30	0	0			
				315	0	0
Salaries and Wages, etc.				1400	0	0
Office-Expenditure:						
Stationery	60	0	0			
Miscellaneous Printing	100	0	0			
Postages and Sundry Expenses	100	0	0			
List of Fellows	10	0	0			
				270	0	0
Grant to Conjoint Board of Scientific Societies (1920 & 1921)				20	0	0
Library (Books and Binding)				150	0	0
Library Catalogue:						
Cards	25	0	0			
Compilation	50	0	0			
				75	0	0
Publications:						
Quarterly Journal (Vol. lxxvii), including Commission on Sale	900	0	0			
Postage on Journal, Addressing, etc.	90	0	0			
Abstracts of Proceedings, including Postage	200	0	0			
Record of Geological Literature	250	0	0			
				1440	0	0
Total Ordinary Expenditure				£3920	0	0
Special Expenditure.						
Quarterly Journal, Vol. lxxvi, pts. 3 & 4	400	0	0			
Compilation of Record of Geological Literature (1914–1919)	300	0	0			
				700	0	0
				£4620	0	0

JAMES VINCENT ELSDEN, *Treasurer.*

January 26th, 1921.

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in the hands of the Bankers at January 1st, 1920:						
Current Account	63	13	9			
Deposit Account	300	0	0			
,, Balance in the hands of the Clerk at January 1st, 1920	12	19	11			
				376	13	8
,, Compositions				157	10	0
,, Admission-Fees:						
Arrears	94	10	0			
Current	315	0	0			
				409	10	0
,, Arrears of Annual Contributions				157	10	0
,, Annual Contributions for 1920:—						
Resident Fellows	1974	10	6			
,, Annual Contributions in advance	137	11	0			
				2112	1	6
,, Publications:						
Sale of Quarterly Journal:						
,, Vols. i to lxxiv (less Commission £7 14*s.* 10*d.*)	123	10	7			
,, Vols. lxxv & lxxvi (less Commission £17 2*s.* 1*d.*)	219	15	6			
Journal Subscriptions in advance	40	3	0			
				383	9	1
,, Other Publications (less Commission)				15	15	5
,, Miscellaneous Receipts				32	0	6
,, Interest on Deposit				30	17	0
,, Dividends, as received:—						
£2500 India 3 per cent. Stock	75	0	0			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	10	10	0			
£2250 London & North-Western Railway 4 per cent. Preference Stock	63	0	0			
£2800 London & South-Western Railway 4 per cent. Consolidated Preference Stock	78	8	0			
£2072 Midland Railway 2½ per cent. Perpetual Preference Stock	36	5	2			
£267 6*s.* 7*d.* Natal 3 per cent. Stock	5	12	4			
£500 5 per cent. War Stock (1929–1947)	25	0	0			
				293	15	6
,, Income-Tax recovered				83	0	10
,, Transfer from the Sorby & Hudleston Bequests				400	0	0
				£4452	3	6

A further sum is due from Messrs. Longmans & Co. for Journal-Sales, etc. £142 19*s.* 2*d.*]

Year ended December 31st, 1920.

PAYMENTS.

	£	s.	d.	£	s.	d.
By House-Expenditure:						
Taxes		15	0			
Fire- and other Insurance	22	9	5			
Electric Lighting and Maintenance	61	17	7			
Gas	34	6	2			
Fuel	83	2	4			
Furniture and Repairs	37	10	1			
House-Repairs and Maintenance	30	2	11			
Annual Cleaning	26	19	10			
Washing and Sundry Expenses	75	13	10			
Tea at Meetings	29	17	2			
				402	14	4
,, Salaries and Wages, etc.:						
Permanent Secretary	550	0	0			
Librarian	250	0	0			
Clerk	200	0	0			
Junior Assistant	62	0	0			
House-Porter and Wife	120	6	0			
Housemaid	36	18	0			
Charwoman and Occasional Assistance	52	4	0			
Accountants' Fee	10	10	0			
Extra Assistance	2	10	0			
,, Office-Expenditure:				1284	8	0
Stationery	80	15	11			
Miscellaneous Printing	142	6	7			
Postages and Sundry Expenses	87	4	10			
				310	7	4
,, List of Fellows				106	15	0
,, Library (Books and Binding, etc.)				107	8	6
,, Library-Catalogue: Compilation				50	0	0
,, Medals (engraving inscriptions)				1	16	6
,, Publications:						
Quarterly Journal, Vols. lxxv & lxxvi, Paper, Printing, and Illustrations	1477	16	11			
Postage on Journal, Addressing, etc.	130	9	2			
Abstracts, including Postage	180	1	6			
List of Geological Literature (on a/c)	90	14	0			
				1879	1	7
,, Balance in the hands of the Bankers at December 31st, 1920 (includes £25 2*s.* 0*d.* not expended of the Grant from the Prestwich Fund for the purchase of Books)	289	7	6			
,, Balance in the hands of the Clerk at December 31st, 1920	20	4	9			
				309	12	3
				£4452	3	6

We have compared this statement with the Books and Accounts presented to us, and find them to agree.

J. FREDK. N. GREEN,
S. HAZZLEDINE WARREN, } *Auditors.*

January 26th, 1921. JAMES VINCENT ELSDEN, *Treasurer.*

Statements of Trust-Funds: December 31st, 1920.

'Wollaston Donation Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1920	32	3	8	By Cost of Medal	10	10	0
" Dividends on the Fund invested in £1073 Hampshire County 3 per cent. Stock	32	3	8	" Award from the Balance of the Fund	21	13	8
				" Balance at the Bankers' at December 31st, 1920	32	3	8
	£64	7	4		£64	7	4

'Murchison Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1920	25	10	2	By Cost of Medal		11	0
" Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture Stock	28	0	2	" Award to the Medallist	10	10	0
" Income Tax recovered	12	0	2	" Award from the Balance of the Fund	28	9	3
				" Balance at the Bankers' at December 31st, 1920	26	0	3
	£65	10	6		£65	10	6

'Lyell Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1920	52	15	3	By Cost of Medal		15	0
" Dividends on the Fund invested in £2010 1*s.* 0*d.* Metropolitan $3\frac{1}{2}$ per cent. Stock	70	7	0	" Award to the Medallist	25	0	0
				" Awards from the Balance of the Fund	44	12	0
				" Balance at the Bankers' at December 31st, 1920	52	15	3
	£123	2	3		£123	2	3

'Barlow-Jameson Fund' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1920	38	0	7	By Balance at the Bankers' at December 31st, 1920	52	1	5
,, Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture Stock	9	16	8				
,, Income Tax recovered	4	4	2				
	£52	1	5		£52	1	5

'Bigsby Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1920	4	1	11	By Balance at the Bankers' at December 31st, 1920	10	7	11
,, Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	4	8	2				
,, Income Tax recovered	1	17	10				
	£10	7	11		£10	7	11

'Geological Relief Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1920	75	8	0	By Grants	6	6	0
,, Dividends on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock	4	3	4	,, Balance at the Bankers' at December 31st, 1920	73	5	4
	£79	11	4		£79	11	4

'Prestwich Trust Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1920	39	13	6	By Balance at the Bankers' at December 31st, 1920	60	13	6
,, Dividends on the Fund invested in £700 India 3 per cent. Stock	21	0	0				
	£60	13	6		£60	13	6

'Daniel-Pidgeon Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1920	50	6	2	By Awards	65	11	10
,, Dividends on the Fund invested in £1019 1*s.* 2*d.* Bristol Corporation 3 per cent. Stock	30	11	4	,, Balance at the Bankers' at December 31st, 1920	15	11	8
,, Interest on Deposit		6	0				
	£81	3	6		£81	3	6

SPECIAL FUNDS.

Hudleston Bequest.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1920	195	8	9	By transfer to General Purposes Account	200	0	0
,, Dividends (less Income-Tax) on the Fund invested in £1000 Canada $3\frac{1}{2}$ per cent. Stock	28	0	0	,, Balance at the Bankers' at December 31st, 1920: Current Account	44	10	10
,, Income Tax recovered	12	0	0				
,, Interest on Deposit	9	2	1				
	£244	10	10		£244	10	10

Sorby Bequest.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1920	195	8	9	By transfer to General Purposes Account	200	0	0
,, Dividends (less Income-Tax) on the Fund invested in £1000 Canada $3\frac{1}{2}$ per cent. Stock	28	0	0	,, Balance at the Bankers' at December 31st, 1920: Current Account	44	10	10
,, Income Tax recovered	12	0	0				
,, Interest on Deposit	9	2	1				
	£244	10	10		£244	10	10

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

JAMES VINCENT ELSDEN, *Treasurer.*
January 26th, 1921,

J. FREDK. N. GREEN,
S. HAZZLEDINE WARREN, } *Auditors.*

Statement relating to the Society's Property.

December 31st, 1920.

	£	s.	d.	£	s.	d.
Balance in the Bankers' hands, December 31st, 1920 (includes £25 2*s.* 0*d.* not expended of the Grant from the Prestwich Fund)	289	7	6			
Balance in the Clerk's hands, December 31st, 1920	20	4	9			
				309	12	3
Due from Messrs. Longmans & Co., on account of the Quarterly Journal, Vol. LXXVI, etc. ..	142	19	2			
Arrears of Annual Contributions .... (Estimated to produce £150 0*s.* 0*d.*)	185	17	0			
				328	16	2
				£638	8	5
Funded Property, at cost price :—						
£2500 India 3 per cent. Stock	2623	19	0			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	502	15	3			
£2250 London & North-Western Railway 4 per cent. Preference Stock	2898	10	6			
£2800 London & South-Western Railway 4 per cent. Consolidated Preference Stock .	3607	7	6			
£2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	1850	19	6			
£267 6*s.* 7*d.* Natal 3 per cent. Stock	250	0	0			
£500 5 per cent. War Stock (1929–1947) ..	475	0	0			
£2000 Canada $3\frac{1}{2}$ per cent. Stock (1930–1950)	1982	11	0			
				£14,191	2	9

[NOTE.—*The above amount does not include the value of the Library, Furniture, and stock of unsold Publications. The value of the Funded Property of the Society, at the prices ruling at the close of business on December 31st, 1920, amounted to £6989 10s. 1d.*]

JAMES VINCENT ELSDEN, *Treasurer.*

January 26th, 1921.

Award of the Wollaston Medal.

In presenting the Wollaston Medal in duplicate to Dr. Benjamin Neeve Peach, F.R.S., and to Dr. John Horne, F.R.S., the President addressed them as follows:—

Dr. Peach and Dr. Horne,—

Since the day, two and twenty years ago, when the Society acclaimed your joint work in the Highlands of Scotland, you have jointly and individually done much to advance our knowledge of the mineral structure of the Earth. It is needless to enumerate this in detail. As Director of the Geological Survey in Scotland, Dr. Horne, you have been responsible not only for much research of your own, but have ably inspired and controlled that of others, and Dr. Peach, as geologist and palæontologist, you have added lustre to the reputation of the service to which you belonged no less than of yourself, and the study of the higher Crustacea of the Carboniferous rocks will especially remain indebted to your researches. Fully aware that each of you had amply earned the highest distinction in its power to grant, believing, too, that any discrimination would alloy the satisfaction of the recipient, the Council decided, with one accord, to revert to a more than sixty-year old precedent, and to award the Wollaston Medal in duplicate. I am confident that the whole Society will be in accord with the Council in this decision, aud it is a great gratification to myself that Fate should have reserved for me the congenial duty of handing these Medals to you in the name of the Council and of the Society.

Dr. Peach in reply, said:—

Mr. President,—

I am unable to express my feelings as to the great honour that the Geological Society has conferred on Dr. Horne and myself in considering that our work has been of such importance that they should have awarded to us, in duplicate, the Palladium of our science, the Wollaston Medal.

It behoves me to say that anything that I have been enabled to do has been mainly owing to my having been a member of the staff of the Geological Survey under the guidance of such a

succession of illustrious chiefs as Murchison, Ramsay, Geikie, and Teall, and in constant association with the other members of the staff.

It has been my great good fortune to have been placed in Scotland, at the very movable verge of a great continental mass, and especially among the older rocks which have retained many traces of the vicissitudes through which our country has passed.

You have been good enough to refer to my palæontological work on the Carboniferous higher Crustacea, which has been a great pleasure to myself. I felt that I had to do something in this field, to justify the training which I received from Huxley and Salter.

I feel deeply indebted to the Geological Society for the constant encouragement afforded to Dr. Horne and myself during our career, an encouragement which now culminates in this expression of their continued goodwill. I beg, Mr. President, to assure you that it is a great pleasure to receive the Medal from your hands during your term of office.

Dr. Horne also replied, in the following words:—

Mr. President,—

To be enrolled as a recipient of the Wollaston Medal jointly with my lifelong friend and brilliant colleague, Dr. Peach, is an honour which I highly prize. Scottish geological problems have always been of absorbing interest, largely owing to their complicated character. They have been studied by many investigators, among whom, in our time, Charles Lapworth stands supreme. He established on a firm basis the zonal method of mapping the older Palæozoic rocks of the Southern Uplands, and his researches in the North-West Highlands threw a flood of light on the tectonics of that region.

We, too, have been fascinated by these problems, and have striven to increase our knowledge of the geological history of the land that we love. It is a source of gratification to us that the Council have deemed our efforts worthy of such signal recognition. Our colleagues who joined in the work share this honour with us, notably Dr. Clough, whose marvellous power of detailed mapping has left a permanent mark on Scottish geology. I feel sure that this award will also be a stimulus to younger workers north of the Border, who now pursue these problems with great enthusiasm.

It is an additional pleasure to me to receive this Medal from the hands of one who has done work of prime importance in elucidating Indian tectonics.

Award of the Murchison Medal.

The President then handed the Murchison Medal, awarded to Edgar Sterling Cobbold, F.G.S., to Dr. Herbert Lapworth for transmission to the recipient, addressing him as follows:—

Dr. Lapworth,—

The Council has awarded the Murchison Medal of the Society to Mr. Cobbold, in recognition of his services in advancing geological science.

At the instigation of your father, Mr. Cobbold undertook a detailed study of the Cambrian rocks of Shropshire, and for many years has industriously worked among these ancient rocks, under many difficulties well known to those acquainted with the district. Owing to the paucity of natural or artificial sections, he undertook extensive excavations to obtain his observations, and trained himself to become a skilled palæontologist. He has, consequently, been able to publish work of the highest importance to the students of Cambrian stratigraphy, and has established the Cambrian strata of Shropshire as the type-sequence for the Cambrian faunas of this country. Besides this, his discovery of the *Protolenus* fauna, and of fossils in beds of older date, previously known only in distant regions, especially in North America, has supplied useful evidence for the correlation of the strata and the establishment of faunistic provinces.

The difficulties in the way of the non-professional geologist are increasing, his opportunities are diminishing, and the amount of previous study needful before useful work can be accomplished grows greater continuously. The number of workers of this class is now much fewer than in the days of the founder of this Medal, and this is a matter for regret; but Mr. Cobbold has shown that valuable work can still be carried out by one who is not, professionally, the holder of a geological appointment. His example will, I hope, encourage others to do likewise with equal success.

Dr. Lapworth, in reply, read the following communication received from Mr. Cobbold :—

'It is with much surprise and gratification I learn that my work upon the Cambrian faunas of Shropshire should be considered sufficiently good to warrant the addition of my name to so distinguished a list of geologists as the recipients of the Murchison Medal, and I sincerely regret that I am unable, for family reasons, to be present to receive and acknowledge it in person. I feel that it is largely due to the attractive nature of my subject, and to my good fortune in coming across representatives of Dr. Matthew's *Protolenus* fauna, that so much honour has fallen to my lot.

'I beg to thank you, Mr. President, and the members of the Council for the encouragement that you have given me, which comes just at a time when it was most needed. I had completed the first object of my investigations; I had lost the advice and encouragement of my friend Prof. Charles Lapworth, and was almost at a standstill; now, by this generous appreciation of my work, I am spurred on to further efforts.

'I hope to have established an order of succession for the Shropshire Lower Cambrian which may be of more than local interest, and possibly serve as a table of comparison for other areas, somewhat analogous to those established for the Middle Cambrian from the deposits of Andrarum and, recently, by Mr. Illing, in the Nuneaton area.

'The elucidation of this sequence was the primary object of the excavations begun in 1907. I then thought that it was merely a matter of a little digging, and the identification of fossils, as I hoped, by friends; there were, however, so many forms previously undescribed or unknown to Britain, that I was constrained to work up for myself the literature of the Cambrian faunas, and to do what I could towards identifying or describing the species.

'It was not until 1920 that I was able to complete the lists of fossils, and prepare my observations for publication. I have received much valuable and kindly assistance from other workers, which, I hope, has always been duly acknowledged, but I should like to repeat here my sense of obligation to Mr. Philip Lake, who was the first to recognize the presence of the *Protolenus* fauna, and thus gave me a reliable basis for further study of the specimens which I had collected.

'I am indeed grateful for the encouragement afforded me by this award, and can only hope that, in any future geological work, I may not prove unworthy of the great honour now conferred upon me.'

Award of the Lyell Medal.

In presenting the Lyell Medal to M. Emmanuel de Margerie, For.Memb.G.S., the President addressed him as follows :—

M. de Margerie,—

The Council of the Geological Society has awarded the Lyell Medal to you in recognition of the numerous and valuable services

by which you have deserved well of the Science. Your books on the Forms of the Earth's Surface, on the Dislocations of the Earth's Crust, and your recension of Suess's work on the Face of the Earth are perhaps more familiar than your work on the geological structure of the Pyrenees and the Jura. Your acquaintance with geological knowledge is immense, and you have been indefatigable in placing it at the disposal of others less fortunately constituted than yourself. As a writer on geology you have been a worthy follower of the founder of the Medal, who, by his writings, did more than anyone, of his time or since, to disseminate the knowledge of, and to inspire interest in, the science of Geology. It is in recognition of these services that the Council has awarded the Medal, and in handing it to you I will add our congratulations on your appointment as Director of the Geological Survey of Alsace-Lorraine and our confidence that the opportunity offered in your new position will lead you to add to the services which you have already rendered.

M. de Margerie replied in the following words:—

Mr. President,—

Never would I have dreamt before this day to receive, from the Geological Society of London, the Medal bearing the illustrious name of Sir Charles Lyell.

The subjects upon which I have been engaged, under the influence of such masters as Albert de Lapparent, Marcel Bertrand, Albert Heim, and Eduard Suess, do not appear specially conspicuous in the writings of Lyell. Is it not a sign of the times that mountain-structure and mountain-sculpture are now in the front rank, among the preoccupations of geologists?

When I look at the imposing list of my forty-seven predecessors, I find among them men who have contributed to the advancement of our science along many different lines, but always by means of personal research. In my own case, however, I fear the friendship of a few English colleagues has been more directly effective in bringing about the decision of the Council than the merits of what I have published. For my work has been, alas! that of an editor and compiler, much more than of an original investigator.

Having been appointed by the French Government to reorganize the Survey of Alsace and Lorraine, I have at last to face problems of a very different character—economic and administra-

tive. I shall do my best to maintain in the prosecution of that Survey the high scientific standard of which the official geologists of the University of Strasbourg have given, in the past, so many examples.

In conclusion, Mr. President, let me state that it is a special pleasure for me to receive the Medal from the hands of a friend whose name has been associated for so many years with the history of the Society, and who has himself contributed so actively to the progress of Geology in the British Empire.

Award of the Bigsby Medal.

The President then handed the Bigsby Medal, awarded to Lewis Leigh Fermor, D.Sc., to Dr. J. Coggin Brown, for transmission to the recipient, addressing him as follows:—

Dr. Coggin Brown,—

The Council of the Geological Society has awarded the Bigsby Medal to your colleague, Dr. Fermor, in recognition of his researches and other contributions to the advancement of Geology. In his monumental work on Manganese in India he not only collected and added to our knowledge of the manganese minerals, describing several new ones, but did much to clarify and extend our knowledge of their origin and transformations. Later his researches on the Kodurite rocks of the eastern part of the Peninsula, and the conclusions that they indicated regarding the change in volume which takes place in the passage from one mode to another of the same norm, led up to his distinction between the plutonic and the infra-plutonic modes of solidification of the same magma, and have given a new aspect to the treatment of several of the more important problems of geological speculation. Henceforward it will be impossible to treat of the origin of mountain-ranges, of earthquakes, or of much of the deformation of the Earth's crust, without taking Dr. Fermor's work into consideration.

In these and other ways he has added to the store of geological knowledge, and, as his colleague, I ask you to receive the Medal on his behalf, and to transmit to him the Council's appreciation of the eminent services which he has rendered to Geology.

Dr. Coggin Brown, in reply, said:—

Mr. President,—

It is a privilege to receive this Medal and to undertake the duty of forwarding it to my friend and colleague, Dr. Fermor. The investigations in which he is at present engaged have led him into a somewhat isolated part of India, and have prevented the receipt of any communication in time for this Meeting. Yet they justify abundantly those terms of the Bigsby Bequest which require from the medallist the promise of future results in addition to the records of a meritorious past. I can assure you that this token of the recognition of his researches will give Dr. Fermor the greatest satisfaction, and I thank the Council of the Society in his name, and on behalf of the Service to which he belongs. It is an additional honour to accept the award from the hands of one so distinguished in the annals of Indian geology as yourself.

Award from the Wollaston Donation Fund.

In handing the Balance of the Proceeds of the Wollaston Donation Fund, awarded to Thomas Owen Bosworth, D.Sc., to Dr. Herbert H. Thomas for transmission to the recipient, the President addressed him as follows:—

Dr. Thomas,—

The Council has awarded the Balance of the Proceeds of the Wollaston Donation Fund to Dr. Bosworth in recognition of his geological work. His older work on the granites of the Ross of Mull and on the Keuper of the Midlands has long been known. Later he turned his scientific knowledge and capacity to the furtherance of the development of mineral resources, but did not allow the claims of industry to damp his devotion to pure geology. More than one publication has shown his especial interest in the problems connected with arid conditions of climate, culminating in the important and instructive contribution to the geology of South America recently presented to the Society. Not only for these services, rendered to Geology, has the Council awarded this recognition, but also for the example which he has held out to others, that devotion to the industrial applications of our science is not incompatible with the advancement of pure geology.

Award from the Murchison Geological Fund.

The President then presented the Balance of the Proceeds of the Murchison Geological Fund to Albert Gilligan, D.Sc., addressing him in the following words:—

Dr. Gilligan,—

The Council has awarded to you the Balance of the Proceeds of the Murchison Geological Fund as a mark of its appreciation of the value of your work in the Millstone Grit of Yorkshire, and especially of your important contributions to our knowledge of the petrography of that formation. While the Lower Carboniferous rocks and their mode of origin have received a full share of attention in recent years, our knowledge of the conditions under which the widespread deposits of the overlying clastic sediments were accumulated is still very imperfect. Your work has already thrown interesting light on the probable source of the material composing these rocks in Yorkshire, nor has it been confined to the study of this formation alone. Your studies of the alluvial deposits and of the Lower Permian rocks in Yorkshire have filled important gaps in our knowledge, and are marked by the same methodical carefulness as that which characterized your principal work. In making this Award, the Council looks forward with confidence to the continuation of your researches.

Awards from the Lyell Geological Fund.

In presenting a moiety of the Balance of the Proceeds of the Lyell Geological Fund to Herbert Leader Hawkins, D.Sc., the President addressed him in the following words:—

Dr. Hawkins,—

During the past twelve years you have been publishing a series of papers on fossil sea-urchins, culminating in the fine memoir on the Morphology and Evolution of the Ambulacrum in the Echinoidea Holectypoida, recently published by the Royal Society. These papers, illustrated by exact and beautifully clear drawings from your own pen, have been characterized by keenness of observation, based on manipulative skill, by originality of method combined with attention to the work of previous authors, and by

a breadth of view which has enabled you to co-ordinate the facts under definite hypotheses. In awarding you a moiety of the Balance of the Proceeds of the Lyell Geological Fund, the Council of this Society recognizes the rare combination of scholarly qualities which your work exhibits. It recognizes also that your papers, while important in themselves, constantly keep in view an eventual systematic revision of the whole class, and it hopes that this award will encourage you to that lengthy and laborious task.

In presenting the other moiety of the Balance of the Proceeds of the Lyell Geological Fund to Cyril Edward Nowill Bromehead, B.A., the President addressed him as follows:—

Mr. Bromehead,—

The Council has awarded to you a moiety of the Balance of the Proceeds of the Lyell Geological Fund in recognition of your geological work, first on the granite of Dartmoor, later in the London district, where you devoted much attention to elucidating the development of the Thames and its tributaries. After an interval, devoted to less pacific activities, you have had put on you the duty of watching the progress of the search for oil in Derbyshire, and of investigating the resources of that and other districts in oil-shales and cannels. In all this you have shown both capacity and devotion, and have added materially to the sum of geological knowledge, in acknowledgment of which, and as an encouragement to further activity, this recognition has been awarded.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT.

RICHARD DIXON OLDHAM, F.R.S.

DEATH has not dealt heavily with us in numbers, but among those whom we have lost during the last twelve months are three of our distinguished Foreign Members, and from the list of our Fellows we miss one master mind of his time.

In the death of Prof. CHARLES LAPWORTH on March 13th, 1920, we have to mourn one who stands in the front rank of geologists, worthy to be placed among the masters of the science. In every branch that he touched—stratigraphy, tectonics, petrology, palæontology, the work that he did was not only brilliantly original and enduring, but it has fertilized, and will continue to fertilize, the research of others.

Born in 1842 at Faringdon, in Berkshire, his early life was spent at Buckland, in Oxfordshire. His education, as well as the professional work which he discharged in the South of Scotland up to the age of 39, appear to have been purely literary, but he managed to acquire for himself a knowledge of science. Interest in the origin of landscape, and in the rocks to which it owes its features, was quickened by his discovery of fossils in strata regarded as barren; and the attraction became insistent between 1866 and 1869, when he began a systematic investigation of the rocks of the Southern Uplands, partly alone, and partly in the company of his friend James Wilson.

He soon saw that the Uplands area was much more complicated than had previously been realized, and that the only way in which its structure could be unravelled was by detailed mapping on a scale larger than had been employed. For such work he was eminently fitted, in the possession of an acute faculty for discriminating minute lithological differences and an excellent memory for lithological types, combined with a good eye for a country and for a fossil, and patience to search and collect exhaustively. Moreover, he was able and willing to supplement published topographical maps by personal survey, making large-scale plans of crucial areas on which there was room to record his own very detailed observations.

The results appeared in a succession of papers, culminating in

the great memoir on the Moffat Series communicated to this Society in 1877. In each of the numerous shale-bands which had been thought to form successive horizons in an ascending series of greywackes, he proved that there was a repetition of lithological types, in some cases in normal, in others in inverted order. Careful collecting of the graptolites, the only fossils, showed that each lithological type was associated with a special fauna which accompanied it in all its repetitions and inversions. Three main faunas were individualized and named after Glenkiln, Hartfell, and Birkhill; and, on comparison with all reliable graptolite evidence in Britain and abroad, checked by his personal travels and observations, Lapworth was able ultimately to correlate these fossils with those known from the Upper Llandeilo, Bala, and Llandovery Series respectively. Thus it was proved that a group of fine black shales, 200 or 300 feet thick, represented a vast thickness of rocks elsewhere, and that the tectonics of the region consisted of a series of inverted and faulted anticlines of the shales peering out among synclines of the Gala greywackes. In spite of the complicated stratigraphy, Lapworth was able to publish fully-measured sections, to subdivide the rocks into smaller groups, and even in some cases to establish graptolitic zones which, with trifling modification, have now become the standard of comparison throughout the world.

In order to test his conclusions, he next took the Girvan rocks in hand—a series of great thickness and variety in lithology, and rich in fossil content, which had been placed high up in the supposed Upland sequence, and, despite their innumerable shells and trilobites, had not been satisfactorily correlated with any part of the 'Silurian' succession in England or Wales. Accurate mapping and exhaustive fossil collection were again employed, and in some of the intercalated strata graptolites were discovered. The mapping, again on a large scale, of lithological types, checked by the contained fossils and especially by the graptolite-bearing bands, revealed the succession in an area of which the stratigraphy was at least complicated as at Moffat. It also showed that the graptolitic bands occurred in the same order as before. It became, therefore, possible to ascertain the relationship between the graptolite faunas and the intercalated shell and trilobite faunas, and to set up in Scotland a fully investigated standard of comparison with 'Silurian' rocks of the type areas of England and Wales.

No generalizations or correlations were stated in the Girvan paper; they were reserved for that on the Ballantrae rocks published in the 'Geological Magazine' in 1889. In this paper correlation was effected with other British and foreign areas, and elaborate and beautifully-executed sections were designed to bring out the variations in thickness of the rocks and the tectonic nature of the whole Upland area, the main features of which were found to be an endocline and a corresponding exocline, the deceptive nature of which had led to the previous misconceptions as to the structure of the Uplands. It was thus demonstrated that the region of the Southern Uplands was one of intensely-complicated Alpine structure, to which it was folly to apply the rules and methods of lowland stratigraphy. The only possible method of unravelling the complication was shown to be elaborate mapping, both lithological and palæontological, on a large scale. The reward of such work was the revelation, both of the physical conditions under which the rocks were formed, and of the succession of life which accompanied their deposition, by means of which it was now becoming possible to zone the Lower Palæozoic rocks just as those of Neozoic age had been zoned.

It still remained to be proved that the zones of the older Palæozoic rocks had the same wide extent and the same reliability as those of newer rocks, and this task had been simultaneously taken in hand. Paper after paper evinced the interest taken by Lapworth in the structure, life-history, and distribution of the graptolites. After clearing up the classification and describing many new species, he published his paper on 'The Geological Distribution of the Rhabdophora,' in which he discussed the geological and geographical distribution of families, genera, and species, illustrating the subject with numerous and elaborate tables, all leading up to the establishment of twenty graptolitic zones, the extension of some of which he was able to trace, in the same order, not only over the United Kingdom, but throughout Europe, and even into America and Australia.

This work finds a fitting sequel in the 'Monograph of British Graptolites' written under Lapworth's editorship by Miss G. L. Elles & Miss E. M. R. Wood (Dame Ethel Shakespear), in which it was shown that the range from the Upper Cambrian to the Ludlow rocks is divisible into thirty-six graptolitic zones. In an interesting paper on the life of the graptolite it was pointed out that the value of this organism for the subdivision of strata, and for

wide-reaching correlation, is due to the fact that all but the earliest forms were epiplanktonic, living attached to floating sargasso-like weeds; and thus, transported by currents, they could reach the most remote areas of ocean and become embedded in the carbonaceous mud resulting from the addition of seaweed material to the sediment there forming.

For the purposes of his work Lapworth appears to have been satisfied with the then current terminology of the Arenig, Llandeilo, and Bala Series, but he found it necessary to link together the Lower and Upper Llandovery with the Tarannon rocks as a single series, which he called 'Valentian.' But his most important contribution to nomenclature was the introduction of the term 'Ordovician,' which he proposed, in a closely-reasoned paper, to comprehend the rocks from the top of the Tremadoc to the base of the Valentian, exclusive, on the ground that they enclose one of the three subequal faunas of the Lower Palæozoic Era. He subsequently advocated the use of this term at the International Geological Congress, and it has now been widely accepted.

In 1881 Lapworth was appointed to fill the newly-established Chair of Mineralogy & Geology at the Mason College, Birmingham, his title being subsequently changed at his own request to that of Professor of Physiography & Geology. He at once began work on the Midland rocks, but found time for two visits to the Highlands of Scotland, which had long attracted him, on account of the manifest obstacles which investigators had encountered there. He foresaw that these difficulties had their roots in complicated tectonics, and he rightly argued that his training in the vast disturbances of the Southern Uplands would be of service in their solution.

In this supposition he was quite correct. The succession from the fundamental gneiss through 'Cambrian' and 'Lower Silurian' to the 'Eastern Schists' was not a simple stratigraphical sequence as had been supposed, but was complicated by inversions, faults, and thrust-planes; the rocks were doubled back upon themselves; and the 'Eastern Schists' were, in his view, a complex group consisting partly of sediments, but mainly of the fundamental gneiss thrust over younger rocks during older Palæozoic time. In his paper entitled 'The Secret of the Highlands, Part I' he gave the evidence on which he relied for the proof of this contention. He proceeded to parallel his structures with those described by

Heim in the Alps, and showed that they were those of the basal wreck of a mountain-range. The scheme foreshadowed by this paper was cut short by severe illness, from which he never recovered sufficiently to regain all his former vigour and endurance. But in a few short notes he indicated some of the further points that he had reached, including a description of the main results of crust-creep, such as the formation of mylonites and augen-schists, and an outline of the theory of dynamo-metamorphism to which he had been led.

Perhaps the main effect on his own mind which resulted from both the Upland and the Highland work was an appreciation of the importance in geological history and tectonics of tangential stress in the earth-crust. This was the key-note of his famous Edinburgh address in 1892, and was again referred to in his Presidential Address to this Society, while the geographical bearing of his 'fold-theory' was touched upon in a paper to the Royal Geographical Society and its time-relations in a lecture to the Geologists' Association.

While at Birmingham Lapworth devoted much time to the geology of Middle Britain, from Leicestershire to Merionethshire, giving most of his energies to the older rocks. He proved the existence of pre-Cambrian rocks at Nuneaton and the Lickey Hills, and enlarged our knowledge as to the nature of the Uriconian rocks of several Shropshire areas. He mapped the Longmynd, made certain that it was of pre-Cambrian age, and divided the succession into two conformable series, the lower of which he paralleled with the rocks of Charnwood Forest and the higher with the Torridon Sandstone. He proved that the Midland Quartzites, like those of the Highlands, were Cambrian, and passed up conformably into grits and sandstones, in which he found and described *Olenellus* in Shropshire and the *Hyolithus* Limestone at Nuneaton, thus proving the existence of Lower Cambrian rocks in England. With Dr. Stacey Wilson he mapped the Lower and Middle Cambrian rocks of the Harlech country. He outlined the position of the Middle and Upper Cambrian shales at Stockingford, and found the first fossils obtained from them. In Shropshire he brought the Ordovician rocks into order, and compared them with those of other regions. He enlarged our knowledge of the Coal-Measures, and studied the question of the 'concealed coalfields,' placing his knowledge at the disposal of the Royal Coal Commission of 1902–1905. He indicated the possibility that the constituents

of the Permian breccias, and of the Carboniferous, Permian, and Triassic conglomerates might have been derived from ancient rocks partly concealed beneath them. Finally, he made numerous contributions to the study of local glaciation, and to the general physiography and river-history of the Midlands.

Naturally, his wide knowledge and his power of grappling with questions in which a correct estimation of cumulative evidence was of value were called for in industrial questions, and there were few of the more difficult mining enterprises in the Central Coalfields in which his advice was not sought and followed with success. The development of these coalfields owes much to his genius and hard work. He was also consulted as to the future prospects and work of the Geological Survey, and gave considerable assistance to the Departmental Committee of enquiry on this subject.

Lapworth joined the Geological Society in 1872, received the award of the Murchison Fund in 1878, the Lyell Fund in 1882 and 1884, the Bigsby Medal in 1887, and the Wollaston Medal in 1899. He served on the Council three times between the years 1894 and 1908, was Vice-President in 1905–1906, and President in 1902–1904. He was elected a Fellow of the Royal Society in 1888, and a Royal Medal was awarded to him in 1891. The Universities of Aberdeen and Glasgow conferred on him the degree of LL.D., and the University of Birmingham on its constitution in 1900 appointed him Mason Professor of Physiography & Geology, and conferred on him the official degree of M.Sc. On his retirement in 1914 he was made Professor Emeritus.

When we take into consideration the amount of scientific work which he personally accomplished, the number of students who passed through his hands, his influence on those beginning or actively engaged in the prosecution of research, and the good seed sown broadcast, with unmeasured generosity, in the fertile soil of contemporary intellect, we may say that the solid contribution made by Lapworth to the service of his science was not less than that of his greatest predecessors.

The guiding star of his life was a passion for truth. The discipline of his imagination, the tireless energy of mind and body, and his skill of hand and eye, were all employed in the best service that he knew, the search for scientific truth and the discovery of the laws of Nature. In the course of his research it was more than once necessary that he should strike hard for the right, to remove impediments in the way of truth, and to advance scientific know-

ledge; but he bore no malice, and there were few indeed among those who had been his scientific adversaries whom he could not in the end reckon as his personal friends. And to his friends no man was ever more genial or more generous. Great as was his joy in his own work, he loved still more to see his students and friends, whom he had endowed with the precious gift of his own ideas, bring home the harvest of the seed which he himself had sown.

At the time when Lapworth's work began an epoch of great discoveries and broad generalizations was passing away, to be succeeded by a period of smaller things, the filling-in of details, the work of the systematist, the species-maker, and the collector of isolated facts. It was the work of Lapworth, not only to show how thoroughly and perfectly facts should be collected, but to institute a new era of co-ordination, to evolve new laws and new principles. To have reduced the Southern Uplands to order was no light task, but to wring from their crumpled rocks the Lower Palæozoic life-succession which has set in order the strata of this age all over the world was a work of genius. To have broken down the reticence of the Highlands was an achievement, but to use the secret that he had surprised as a key to the tectonics and location of mountains and volcanoes, to the build of continents and oceans, and to the very structure and life-history of the planet itself, is evidence of a vigour of intellect which could not only link Geology again with the sciences of Physics, Biology, and Geography, but could afford to discover a new continent as a by-product of its activity. [W. W. W.]

Joseph Paxson Iddings was born in Baltimore in 1857. He was of Quaker stock on his father's side, and both parents had refined literary tastes, so that his early environment was that of a cultured home.

His scientific life divides itself naturally into three periods. From 1880 to 1895 he was attached to the Western Division of the United States Geological Survey, from 1895 to 1908 he was Professor of Geology in the University of Chicago, and from 1908 until the end he devoted himself to private work, living in his country house at Brinklow, Montgomery County (Maryland). For the greater part of the first period he was a member of the staff employed in surveying the Yellowstone National Park and adjoining districts—a position which gave him the opportunity of

studying the remarkable series of Tertiary igneous rocks for which that region is so justly celebrated. How well he made use of that opportunity is shown in his numerous memoirs and papers in the various publications of the United States Geological Survey, especially the great monograph on 'The Geology of the Yellowstone National Park' (1899), and also in the 'American Journal of Science,' the Bulletin of the Philosophical Society of Washington, and other scientific periodicals. His memoir on 'The Eruptive Rocks of Electric Peak & Sepulchre Mountain' may be taken as an example of his work during this period (Annual Report, 1892), and also his communication to our Journal on 'Extrusive & Intrusive Igneous Rocks' (1896), made shortly after his election as Foreign Correspondent. Work of this kind brought Iddings face to face with the general problem of 'The Origin of Igneous Rocks,' and accordingly we have an important memoir by him on this subject in a Bulletin of the Philosophical Society of Washington (1892).

In 1895 Iddings left the United States Geological Survey, in order to take up the Professorship of Geology in the University of Chicago. He now became greatly interested in the classification of igneous rocks, and acting in association with Whitman Cross, Pirsson, and Washington, took a large share in devising and elaborating the well-known 'Quantitative System.' This is not the place to consider the merits and demerits of that system, but one statement with reference to it may be confidently made. It has exerted a great influence on petrological thought, and many of the terms introduced by its authors have become definitely established in literature. During the period that we are considering, Iddings paid much attention to the use of graphic methods as an aid to the interpretation of chemical analyses, and devised, among others, a method of expressing in a composite diagram both the composition of individual rocks and the chemical relations of igneous rocks as a whole. This diagram enables many important relations to be easily apprehended; for example, it shows at a glance, from the absence of clustering, that it is hopeless to look for any natural classification of igneous rocks based on chemical composition. It was first published, along with others constructed on different principles, by the United States Geological Survey ('Professional Paper,' No. 18, 1903), and afterwards reproduced in his book on 'Igneous Rocks.' During this period he also brought out a work on 'Rock-Minerals' for the use of students, which took the place

of his translation and abridgment of Rosenbusch's 'Mikroskopische Physiographie der Petrographisch Wichtigen Mineralien,' published in 1888.

We have now reached the third and last period of his scientific life. The first few years were largely occupied in the preparation for publication of his treatise on Igneous Rocks, the material for which had no doubt been mainly collected during the previous period. The first volume, dealing with general principles, appeared in 1909, and the second—a systematic description of igneous rocks, with special reference to their chemical and mineralogical characteristics—in 1913. In 1914 he delivered the Silliman Memorial Lectures, which were published in the same year by the Yale University Press under the title of 'The Problem of Vulcanism.'

Iddings travelled widely, and always with the object of increasing his knowledge of igneous phenomena past and present. He visited England on several occasions—first towards the end of the eighties of last century, and finally in June 1914, when he delivered a course of lectures at University College. During one of these visits the present writer spent two or three days with him in North Wales, where he became much interested in the Palæozoic equivalents of the Tertiary rhyolites of Yellowstone Park which he had recently studied. On leaving us in 1914, he succeeded, despite the war, in carrying out a plan which he had formed of visiting the East Indies and some of the volcanic islands of the South Pacific.

He had been elected a Foreign Correspondent in 1894 and Foreign Member in 1904.

He made lasting friendships wherever he went, both with the old and with the young. Although unmarried, he was fond of children, with whom he rapidly established cordial relations, delighting them with stories of the Far West and other places that he had visited. He was a careful, conscientious, philosophic worker, with many interests outside his own special subject, such as music and other branches of Natural History. He made no secret of his sympathies with us during the war, and took pleasure in hoisting the Union Jack alongside the Stars and Stripes at his country house on 'British Day.' Shortly before his death on September 8th, 1920, at Brinklow, he wrote an introduction to a posthumous volume of poems by his sister, Lola La Motte Iddings, a blithe spirit whom it was also a privilege to know. It concludes with a quotation from one of the poems—'Up Spirit! Greet the new day with a song.' [J. J. H. T.]

The death of our Foreign Member, Sven Leonhard Törnquist, deprives our science of one who contributed largely to the knowledge of the Lower Palæozoic rocks of his native country, especially, in the provinces of Dalecarlia and Scania.

He was born on March 6th, 1840, at Uddevalla, and completed his education at Lund University, and at the same time undertook research-work in the neighbourhood of that University, as the result of which he was awarded the Ph.D. degree in 1865. Shortly afterwards he obtained the post of Lektor in a school at Gefle, and while there carried on most of his work in the tract of Lower Palæozoic rocks around Lake Siljan. A number of papers were written by him dealing with the stratigraphy of these very complex deposits, and he also added largely to the elucidation of their palæontology. Especially noticeable are his contributions to our knowledge of the fauna of the *Leptæna* Limestone, the stratigraphical position of which was for many years undetermined. While engaged in the study of the Dalecarlian deposits, he travelled widely in his own country and elsewhere, and contributed papers on Ostergothia and Scania, also on the Vogtland, Thuringia, and Great Britain.

As a result of his visit to this country in 1878, he made a comparison of the ancient rocks of Sweden with those of Great Britain, which was published in Stockholm in the following year. The study of graptolites was essential to the unravelling of the Dalecarlian deposits, and he possessed a wide knowledge of these organisms. In 1882 he left Gefle for Lund, and thereafter devoted especial attention to the graptolites, issuing from time to time a series of luminous papers and memoirs, which placed him in the first rank as a student of the group, as regards both their structure and their stratigraphical importance. He received the title of Professor in 1902. He resigned his position as a teacher in 1905, but continued his researches, and his last paper was published a short time before his death on September 6th, 1920. He was elected a Foreign Correspondent of our Society in 1893, and a Foreign Member in 1900.

He was singularly modest, and ever thoughtful for others. His friends owe much to him. No trouble was too great for him, when showing other geologists over his ground, and there are many in this country, as elsewhere, who have reaped stores of knowledge from personal acquaintance with him, and who will ever remember his kindliness and courtesy. [J. E. M.]

Alfred Gabriel Nathorst was for many years Director of the Palæobotanical Museum of the Swedish Academy, one of the very few institutions in the world devoted to the study and exhibition of fossil plants. Shortly before his retirement Dr. Nathorst had the satisfaction of seeing the completion of the new building, an event to which he had long looked forward with great eagerness, and the appointment as Director of his old pupil and assistant, Dr. Halle. The Stockholm Museum was the Mecca of palæobotanists, and those who were fortunate enough to make the pilgrimage returned with feelings of admiration and envy.

Nathorst was a good geologist and systematic botanist, an experienced Arctic explorer and geographer, pre-eminent in his exceptionally wide knowledge of palæobotany. There are few men who have left behind them a worthier monument of scientific achievement in the course of a life consistently and whole-heartedly devoted to research. He took a leading part in building up palæobotanical science, not only by his own investigations, but by the sympathetic and ungrudging help that he was always ready to give to younger men. In a letter of acknowledgment of the award of the Lyell Medal he spoke of his first visit to England at the age of twenty-one, when he first met Sir Charles Lyell, as 'one of the most highly-prized reminiscences' of his youth. 'It was Lyell's "Principles of Geology,"' he wrote, 'which first excited my love for Geology.' Since 1872 he had paid many visits to this country. In 1907, as one of the more distinguished Foreign Delegates at the Centenary Celebration of our Society, he received at Cambridge the Honorary degree of Sc.D. He was an ideal guest: thoroughly at home in a land for which he had a real affection; despite his inability to hear the spoken word, by his quickness in reading the deaf-and-dumb alphabet or grasping the meaning of partly-written sentences, he almost made one forget his infirmity. He spoke and wrote English with wonderful correctness, and was familiar with certain favourite English authors, notably Dickens and Kipling.

Nathorst's scientific activity was amazing. His first paper was published in 1869, and his last contribution, 'On the Culm Flora of Spitsbergen,' appeared in 1920. In 1882 he went to Spitsbergen, and in 1898 he conducted an expedition to Bear Island and other Arctic lands and circumnavigated Spitsbergen. In a two-volume book published in 1900, he described his Arctic experiences during two summers in Northern ice-seas.

His contributions comprise papers on stratigraphical geology, notably his admirable memoir on the Geology of Spitsbergen and other Arctic regions; palæozoology, including his account of the remarkable Cambrian impressions of Medusæ; systematic botany, and plant geography, numerous papers on fossil plants ranging from Devonian to Pleistocene floras. Whatever he did was done with admirable thoroughness; while careful of details he took a broad philosophical view, and presented his results in a concise, lucid style, whether he wrote in Swedish, French, English, or German. Among his better-known researches reference may be made to his classic papers on the origin and nature of many of the so-called fossil Algæ, his work on the older Palæozoic floras of Bear Island, Spitsbergen, the Falkland Islands, Norway, and other regions, on the earlier and later Mesozoic floras of Scania, the Yorkshire coast, Japan, Mexico, Kotelny Island, and other parts of the world, on the Tertiary and post-Tertiary floras of Japan and Northern Europe, his description and application of improved methods of examining the cuticles of carbonized impressions, and his numerous essays on questions of general scientific interest.

Nathorst's death is a very serious loss to Geology in the fullest sense; he will be missed by a wide circle of friends, who felt for him not only the respect due to a master, but a sincere affection inspired by his generous nature and by a personality characterized by a permanently youthful enthusiasm and a joyous devotion to research. He was elected a Foreign Correspondent in 1885, a Foreign Member in 1893, received the Lyell Medal in 1904, and died on January 20th, 1921, at the age of seventy years.

[A. C. S.]

Sir Lazarus Fletcher was born at Salford on March 3rd, 1854, and educated at Manchester Grammar School and Balliol College, Oxford. He early developed a talent for mathematics, whence he was led first into physics, and then through crystallography into mineralogy. In 1878 he was appointed assistant in the Mineralogical Department of the British Museum, and in 1880 was made Keeper of that Department. As such, one of his first duties was the transfer of the whole of the mineral collection from Bloomsbury to South Kensington, and its rearrangement in its new home. This task was taken up with characteristic energy and thoroughness, a talented staff was collected round him, the Department equipped with the needs for mineralogical research,

and the public collections arranged with a perfection of specimens and arrangement which has never been surpassed, while the value and interest of the whole was enhanced by the lucidity of the written descriptions and guides to study of the collections. His manifold administrative duties did not wholly engross his attention, and he found time for independent research, of which the most important was his investigation of the transmission of light through crystals, leading up to his memoir on Optical Indicatrices, published in 1892. In this his mathematical training enabled him to elucidate the interpretation of his observations, to clear up a subject which had been previously ill understood, and to place an invaluable means of research at the disposal of workers at mineralogy or petrography. When he was made Director of the Natural History Museum in 1909, advancing years and a severe illness had deprived him of much of his former energy; but he still retained his quiet studious character, ever helpful to all enquirers, with a kindly tolerance and genially cynical outlook on affairs. Among his services to Geology special mention may be made of his interest in the Mineralogical Society, which owes much to his inspiration and work as President and Honorary Secretary. His merits were not unrecognized, he was elected a Fellow of the Royal Society in 1889 and a Vice-President in 1910, was a foreign and honorary member of numerous scientific societies, a recipient of several honorary degrees, and received knighthood in 1916. He was elected Fellow of our Society in 1879, was Vice-President from 1890–93, and the Wollaston Medal was awarded to him in 1912. He was superannuated from his official position in 1919, and died unexpectedly of heart-failure on January 6th, 1921.

Henry Hoyte Winwood, who died at Bath on Christmas Day 1920, ten days after he had completed his 90th year, was for long a familiar and welcome figure at our meetings. Graduating from Exeter College, Oxford, in 1852, he was admitted to holy orders, but only held a curacy for three years. Always an ardent geologist, he was the author of several papers devoted to the local geology of his district, and of the accounts of the geology and meteorology of Bath, prepared for the 1888 meeting of the British Association, but his published writings are no measure of the services which he rendered to Geology and to the Society. He took a keen interest in the geological collection of the Bath

Royal Literary & Scientific Institution, and did much to enlarge it. Of the 55 years during which he was a Fellow of our Society he served for 20 years as a valued, and valuable, member of its Council, and was twice elected Vice-President. Not many of our Fellows have deserved better of the Society, and few will be more sincerely esteemed and regretted by all who knew him.

In WHEELTON HIND the Society loses one who was not only a keen geologist, but an outstanding personality. Possessed of extraordinary energy and application he attained eminence in his own profession and, as a bye-product, threw off an amount of valuable geological work, which would have made a creditable life-record for many an ordinary individual. Of clear and definitely-formed opinions, and not reticent in expressing them, he frequently aroused dissent and opposition, but in still greater degree inspired enthusiasm and help. Through all, his dominant desire was the elucidation of the truth; ever sympathetic and helpful to those who wished for assistance and advice, he never lost the respect even of those most antagonistic to his opinions.

Born at Roxeth near Harrow, in 1860, he received a medical training, and set up in practice at Stoke-on-Trent in 1884. He was, at that time, already interested in geology, and at once began to search the colliery pit-banks of the district for fossils, obtaining what information he could as to horizons from the miners. His first geological publication, in 1889, was an account of 'The Natural Features & Geology of Suffolk' in his father's work on the 'Flora of Suffolk': but in the same year there appeared, in the Transactions of the North Staffordshire Naturalists' Field-Club, the first of a long series of papers, embodying the results of his own observations and researches, on the Carboniferous rocks and fauna. He devoted himself to the unravelling of the succession of the Carboniferous rocks of his district, which was modified by his establishment of the Pendleside Series as a distinct member, lying between the Carboniferous Limestone and the Millstone Grit, and, later, he extended his conclusions to other regions. Recognizing that the basis of satisfactory stratigraphical work was the discovery of a series of life-zones, he perceived the necessity of a re-investigation of the Carboniferous mollusca, and produced his monographs on the Lamellibranchiata.

His geological work was interrupted by a call from the War Office to raise a battery of Garrison Artillery, which he recruited

in three weeks, brought to a high state of efficiency, and led to the Western Front, where it saw some hard fighting in important engagements. He was not long permitted to devote his energies to combatant duty, but was recalled to the work for which he had special qualifications, in the Army Medical Service. Released from this he returned to Stoke-on-Trent, after four years' absence, and resumed the issue of geological and palæontological papers, which reached a total of over 80 in all, produced during a period of 30 years, four of which were spent in military service. He was elected a Fellow of this Society in 1891, received an award from the Lyell Geological Fund in 1902, the Lyell Medal in 1917, and died on June 21st, 1920.

John Udall, who died on October 17th, 1920, aged 79, was a well-known personality among Midland geologists. For over 30 years he was the trusted and valued friend of Charles Lapworth, and his constant companion in the field. Born in London, he passed his studentship at Peterborough Training College, and from 1875 to 1908 served under the Birmingham Education Board, first as Head-Master at Rea-Street School, and subsequently at Dudley-Road School, until his retirement in 1908. He entered largely into the communal life of Birmingham, and, though not contributing to their publications, was an active member of several local scientific and literary societies. He was elected a Fellow of our own Society in 1887. [W. G.]

Alexander Gordon Milne Thomson, youngest son of James Thomson, engineer, Dundee, was born at Landernau (Finistère), France, in 1866, and educated in Dundee. During his school-days he was interested in geology, and at College it became one of his special subjects of study. In association with his brothers he was actively engaged in business throughout his life; but, as he took no part in outdoor sports, he devoted his spare time to the study of problems connected with the Old Red Sandstone. He found great pleasure in examining the fine sections of this system in the counties of Perth and Forfar, in the basin of the Moray Firth, in the Pentland Hills, and in the tract extending from Muirkirk by Lesmahagow to Lanark.

His observations in the field led him to publish a volume on 'The Position of the Old Red Sandstone in the Geological Succession,' wherein he departed from the accepted views regarding the

stratigraphical position of the divisions of this system and their relations to older and younger formations. He contended that the conditions under which the Old Red Sandstone was accumulated may not have been of the character of inland lakes having no connexion with the sea, and that these conditions may have been in operation before the close of Silurian time and after the beginning of the Carboniferous Period. He held that the youngest Silurian rocks, a portion of the Old Red Sandstone, and some of the oldest Carboniferous strata may have been deposited contemporaneously.

This volume formed his only contribution to geological literature. His highly speculative views did not meet with a cordial reception, due largely to his lack of appreciation of the value of palæontological evidence and of the importance of the accurate determination of the geological structure of the areas with which he dealt. He was full of enthusiasm for geological speculation and fond of discussing his peculiar views, always in a genial tone.

He was elected a Fellow of this Society in 1901, and died on December 5th, 1919. [J. H.]

Arthur John Charles Molyneux, a pioneer in Rhodesian geology, possessed an inherited bent for the science, his father, William Molyneux, a former Fellow of our Society, having done much good work in his time, first at home, and afterwards in South Africa. The son, born about 55 years ago, was trained as a mining geologist, and was one of the band of adventurous spirits who entered Matabeleland as soon as it was opened for prospecting in the early nineties. He remained a devoted Rhodesian for the rest of his life, making Bulawayo his home or headquarters, and, by various exploring trips, both north and south of the Zambesi, he acquired a wide and often exclusive knowledge of the general structure of little-known regions. In 1903 he contributed to our Journal an excellent paper on 'The Sedimentary Deposits of Southern Rhodesia,' and in 1905, in a communication to the Royal Geographical Society, he discussed 'The Physical History of the Victoria Falls,' based on his personal investigation—being the first to give a scientific account of the wonderful spectacle, and to explain its origin. In 1909 he brought before our own Society a paper 'On the Karroo System in Northern Rhodesia,' which described for the first time a region hitherto unexplored geologically. Other papers were published by him in South African scientific journals, including several in the Proceedings of the Rhodesia Scientific

Association. During the last few years of his life he was attached as Geologist to the Geological Survey of Southern Rhodesia, and was the author of two of its recently-published Reports. His discovery of the chalcedonized fossils at the base of the Kalahari Sand, described recently by Mr. R. B. Newton,[1] affords an important clue to the age of the South-African plateau.

By his personal influence, as well as by his writings, Molyneux rendered great service in fostering the growth of science in a new country, where it is now a strong plant. He was active in promoting the establishment of the Rhodesia Museum at Bulawayo, and was one of the founders and mainstays of the Rhodesia Scientific Association, which he served at one time as President and continuously in other capacities. Through all the hardships and vicissitudes of a pioneer's life, his placid and kindly disposition remained unimpaired, and gained him friends everywhere. He was among us at the beginning of the present Session, having undertaken a short visit to England in the hope that the voyage and change might recuperate his failing health. He was elected a Fellow of our Society in 1897, was a recipient of the Wollaston Donation Fund in 1909, and died suddenly on December 28th, 1920, almost immediately upon his return to Bulawayo.

[G. W. L.]

James Reeve was born in 1833. Joining the staff of the Norfolk & Norwich Museum as an Assistant in 1847, he was appointed Curator five years later, resigning that office in favour of Mr. F. Leney in 1910, but holding the position of Honorary Curator until his death. His interests were widespread, and much of his work, therefore, was extra-geological, but he made a large collection of fossil mollusca from the Norwich Crag, one or two of them being new to science, and still bearing his name, as does the collection itself, which is preserved in the Norwich Museum.

He collaborated also with the Rev. J. Gunn in the study and arrangement of the latter's unrivalled series of mammalian fossils from the so-called 'Forest-Bed' of the Cromer coast and elsewhere, as he did also with that of the finest collection of raptorial birds in the world (formed by the late J. H. Gurney, and presented by the latter to the Norwich Museum), as to which there is preserved in its Library a ponderous volume of correspondence between Gurney and Reeve, dating from 1856 to 1890.

[1] Ann. & Mag. Nat. Hist. ser. 9, vol. v (1920) pp. 241–49 & pl. viii.

Of the type-forms of the fossils referred to, an important list was published by Mr. Leney in the 'Geological Magazine' for 1902, in the introduction to which Dr. Henry Woodward alludes to Reeve in the following words:—

'It speaks volumes in praise of the Curator that so large and varied a series of type-specimens should have been preserved intact for 50 years or more, and have survived a removal from the old Museum buildings in St. Andrews Street to their present home in Norwich Castle, during all that long period under the care of one man, their excellent Curator, Mr. James Reeve.'

This testimonial, from so distinguished an expert, will be endorsed by all those who have watched Reeve's career for many years.

He will be best known, however, for his interest in art, and for his intimate and critical knowledge of the works of the Norwich School of Painting, as to which he was a widely-recognized authority. He made important collections of Norwich paintings for others as well as for himself; some of those are now in the National Gallery, while others have been left by will to the Museum to which his life was devoted. He became a Fellow of the Geological Society in 1901, and died on December 19th, 1920.

[F. W. H.]

Alexander Montgomerie Bell was a classical scholar in his younger days, and gained the Gainsford Prize for Greek verse when at Balliol. Then he took to Natural Science, and became specially interested in prehistoric archæology, in Pleistocene plants, and in Coleoptera. He was a great collector, his fine series of Chellean implements and other Palæolithic specimens being now possessed and valued by the Pitt-Rivers Museum. He wrote a number of papers published in various other periodicals, as well as one on human remains from Wolvercote in our Quarterly Journal. He was President of the Ashmolean Society in Oxford, and also of the Oxford Anthropological Society. A kindly man, an enthusiastic supporter of Eoliths, and a good friend to Geology, he was elected a Fellow of our Society in 1899, and died on July 13th, 1920.

[W. J. S.]

William Watts, late Waterworks Engineer to the Corporation of Sheffield, belonged to a class of men not uncommon in the North, who have raised themselves to a high position in very adverse circumstances, and is an example to others, showing how

it is possible for them to educate themselves so as to become fit for higher work and responsibilities. He began life as a bricklayer's labourer, unable to read or write. He taught himself both reading and writing, then he became a ganger in the construction of waterworks, and, as this occupation did not allow of sufficient time for further education, joined the police force. Here he found time to learn the rudiments of science in various Mechanical Institutes, to master mechanical drawing and the principles of Civil Engineering. Returning to the waterworks, he made himself so useful that he became the Resident Engineer at one of the reservoirs. Then he attended the evening lectures in engineering and geology at Owen's College (now the University of Manchester) under Prof. (now Sir William) Boyd Dawkins. He was a student for some years, and distinguished himself by his ability and perseverance. He also studied other subjects—including Natural History—and carried on independent microscopical researches for his own pleasure. After this he joined the Manchester Geological & Mining Society, and contributed many papers, chiefly relating to geology and the construction of reservoirs. Next he was appointed Waterworks Engineer to the Corporation of Oldham, and constructed three new and successful reservoirs; lastly, he became Waterworks Engineer at Sheffield, a position which he held until his resignation on account of advancing years. He was elected a Fellow of this Society in 1874, and died on June 20th, 1920, highly honoured by all who knew him, and deeply regretted by the engineers and geologists of Manchester and the surrounding districts. [W. B. D.]

William Augustus Edmond Ussher was born on July 8th, 1849, joined the Geological Survey of England in April 1868, at the age of 19, and for over forty years was an active member of it. At one time or another engaged in various parts of England, his principal service to Geology was rendered in, and his name is more especially linked with, the South-Western counties. Here, in a country of extreme structural complexity, he did much to unravel the correlations of the Trias and Carboniferous rocks of Devon with those of other parts of England, and, in conjunction with Champernowne, worked out the succession and subdivision of the Devonian rocks. The results of his work are recorded in numerous papers, published for the most part in our Quarterly Journal, in the Memoirs of the Geological Survey, and in the

Transactions of the Devonshire Association. After his retirement from the Geological Survey his active geological work came to an end; but he retained his interest in Geology and his connexion with the Society up to the time of his death on March 19th, 1920. He had been elected a Fellow of this Society in 1868, and in 1894 received the Murchison Medal.

John Alfred Codd, by profession a consulting physician in Wolverhampton, devoted much of his leisure-time to Geology. He took great interest in the geological collections of the Frazer Museum, was President of the South Staffordshire Naturalists' Field-Club, and a member of the Geologists' Association, taking part in its excursions. While on one of these he was suddenly taken ill, and died on April 3rd, 1920, after an operation, regretted by all who knew him. He had been elected a Fellow of our Society in 1919.

Wynne Edwin Baxter was born at Lewes in 1844, and in 1867 established himself as solicitor in that town. In 1877 he was appointed High Constable of Lewes, and subsequently held public office in various capacities, for the last 40 years as Coroner for East London. Of equable and judicial temperament, orderly and earnest in his methods of work, he accomplished much, not merely in his public offices and private profession, but also in the varied subjects to which he devoted himself. An enthusiastic collector and student of Milton, and an Egyptologist of some accomplishment, his special interest lay in the study of the Diatomaceæ, of which he amassed an extensive collection. Interested also in Bibliography and Palæography, he produced several works, some legal, but mostly literary, or dealing with the subjects in which he was interested. He was elected a Fellow of our Society in 1879, and died on October 1st, 1920, regretted by numerous friends to whom he had endeared himself by his quiet unassuming manner, sound judgment, and imperturbable demeanour.

John Gerrard, whose death took place at Warley, Manchester, on September 28th, 1920, at the age of 70, was by profession a mining engineer. Appointed Inspector of Mines in 1874, and Chief Inspector of Mines for Manchester and Ireland in 1892, he continued to hold that position until his retirement in 1914. Apart from his purely professional duties, he took a keen interest

in Geology, and accumulated a collection which was presented to the Wigan Technical College. He became President of the Manchester Geological & Mining Society in 1904, and was elected Fellow of our own Society in 1907.

Henry Nathaniel Davies was for fifty years resident at Weston-super-Mare, where he worked as a tutor and teacher in local schools, and did much to arouse local interest, by lectures and personal advocacy, in the geology and prehistoric archæology of the district. To this local interest and to his agency we owe the preservation of the skeleton of a Palæolithic woman, found in Gough's Cavern, of which a description was published in our Quarterly Journal. He was a keen naturalist and collector in Geology and Archæology, his collection being now in the possession of the University of Bristol. Elected a Fellow of this Society in 1889, he died on February 6th, 1920.

Francis James Bennett was born in 1845, and educated at University College School, London. Son of a solicitor, and grandson of the Rev. James Bennett, a noted Syriac and Hebrew scholar, he joined the Geological Survey in 1868, and retired in 1899. During this period his service was almost exclusively confined to the Home and Eastern Counties. In his later years he devoted some attention to Prehistoric Man, and his name will be associated with that of Mr. Benjamin Harrison in attempts to solve the problem of the Eoliths of the Kent Plateau. He also published papers on the application of geological knowledge to road-making and sanitation, and, in 1907, brought out an interesting account of the Ightham neighbourhood, in which he dealt with the geology, river-development, and archæology. He was elected a Fellow of this Society in 1875, and died on June 23rd, 1920.

Arthur Sopwith, son of Thomas Sopwith, a geologist of repute and formerly Fellow of the Society, was born in 1843, took up the profession of mining engineer, and from 1864 to 1873 worked successively in Spain, in Central India, in Bohemia, and in Brazil. In 1873 he was appointed manager of the Cannock Chase Collieries, a post which he vacated in 1919 to become consulting director. As colliery manager he was a pioneer in the introduction of electric lighting in coal-mines, and devoted a large share of his time to improvements in the safety of mining and the social welfare of

the miners. He was elected a Fellow of our Society in 1868, served on the Council in 1902–1903, and died on December 13th, 1920.

George Hogben, born at Islington in 1853, graduated at Cambridge in 1877, and entered the teaching profession. In 1881 he went to New Zealand as mathematical and science-master of the Christchurch Boys' High School, and, after holding some other posts, was made Inspector-General of Schools under the New Zealand Education Department, up to his retirement in 1915. His natural bent was mathematical and physical, and he found time to prepare and publish a number of papers dealing with these subjects, despite his activity in educational matters. It was from this side that he touched our science, by his contributions to the study of New Zealand earthquakes, and by his exertions in rousing an interest in Seismology, both the older and the new, in Australasia. He was elected a Fellow of our Society in 1911, and died on April 26th, 1920.

George Sweet was born at Salisbury, but spent most of his life in Australia, where he was a manufacturer of pottery. He was always a keen geologist, and served as second in command to Sir T. W. Edgeworth David in his expedition to Funafuti. He made extensive collections of fossils from the Carboniferous and Cretaceous rocks of Queensland, and was joint author with C. C. Brittlebank of a description of the glacial deposits of the Bacchus Marsh District. He was elected a Fellow of this Society in 1890.

In the preparation of the foregoing notices of deceased Fellows I am indebted to Sir William Boyd Dawkins, Dr. Walcot Gibson, Mr. F. W. Harmer, Dr. John Horne, Mr. G. W. Lamplugh, Prof. J. E. Marr, Prof. A. C. Seward, Prof. W. J. Sollas, Sir J. J. H. Teall, Prof. W. W. Watts, and many others, too numerous to mention in detail, for assistance and information readily rendered. To all these I express my gratitude and thanks for the help accorded.

ΓΝΩΘΙ ΣΕΑΥΤΟΝ.

'Know your Faults.'

Custom has decreed that on these occasions your President shall deliver an address, which is usually devoted to a review of the past history, of the present condition, or of the future needs of some department of Geological Science. To-day I propose to follow neither of these courses, but to make a digression into the philosophy of our science, to examine the meaning of some of the words which we use, and to take for my text that motto which, blazoned in letters of gold from the ancient temple of Delphi, may be translated by geologists as 'know your faults.'

Faults there are, and many, of observation, of description, of interpretation, but they will only be considered in connexion with faults in the technical meaning of fractures of rock, along which movement of the opposite sides has taken place. These, as the text-books tell us, are of two kinds, normal or reversed; the classification arose in the coalfields of England, where the phenomenon was first studied in detail, and where, with few exceptions, the hade of the fault is towards the downthrow, so that it was natural to regard this as the normal condition, and a 'normal' fault was synonymous with one in which the hade was towards the downthrow, the exceptional cases in which the reverse condition of a hade towards the upthrow was found being distinguished as 'reversed.'

So long as the nomenclature was confined to the region in which it originated, or so long as the purely geological connotation of the words was remembered, no harm could result from the terms made use of; but thought is by no means free, it is trammelled by the limitation of the human intellect and the impossibility of omniscience, by limitation of our vocabulary, and also by the variation in the meaning of words, according to their context or the occasion on which they are used. As a consequence of this, the 'normal' fault came to be regarded as normal in the untechnical sense of the word; the generalization was extended from the district in which it originated to the world at large, and text-books, even those of quite recent date, are found insisting on the prevalence of 'normal' faults and the rarity of reversed ones—yet it is very doubtful whether any such disparity of frequency really exists. Were I to draw on my own experienc

alone, the conclusion would be the opposite, that reversed faults were the normal condition and the so-called 'normal' faults comparatively rare; this I find has equally been the experience of some other geologists whose detailed field-work has been mainly beyond the British Isles, but as a world-wide generalization it would probably be as incorrect as the opposite. The real truth appears to be that the prevalent type of faulting varies in different regions, and that there is not at present sufficient evidence to show which can be regarded as more frequent and therefore more normal in the ordinary sense of the word, or whether, taking the world as a whole, the one is not about as frequent as the other.

A few years ago, I had experience of what may be regarded as an instance of the effect of the double meaning of the word 'normal.' At that time I was interested in the amount of the vertical throw of faults, which had demonstrably originated as normal or reversed, in the special geological meaning of these words. The conditions of the enquiry excluded that large group of faults where the inclination from the vertical is so small that a transference from one class to the other might have been produced by tilting subsequent to the formation of the fault; and of those not so excluded instances of reversed faults with throws of 6000 to 10,000 feet were on record, but I could find none of a definitely normal fault of more than about a couple of thousand feet. Yet it would have been dangerous to conclude that the possible limit of vertical throw was markedly less in the case of 'normal' than of 'reversed' faulting, for the alternative interpretation was equally possible, that, where the fault was normal, the observer saw no reason for emphasizing what might be understood without special mention; while, if the fault was reversed, it was a matter for record, as something out of the common.

In this instance the former interpretation may be the true one, and the limit of possible vertical throw of a definitely normal may be much less than in the case of a definitely reversed fault, or of the intermediate class of those having so small a hade that their original classification is uncertain; but this question will not be treated here. At present I am not concerned with theories of the origin of faults, but with a consideration of the meaning of the words employed to describe them, and among those having a special meaning in geology, which have already been used, we may find examples of the opposite extremes of safety or danger. The word 'hade' is a good example of the former class.

It has a perfectly definite and precise meaning, as the inclination of a sloping surface, measured from the vertical; apart from an obsolete use in agriculture, the word is restricted to mining or geology, and, consequently, it is free from any risk of being misunderstood, for it either carries with it a definite and precise intention, or is absolutely meaningless to the reader or hearer. As an example of the other class we may take the word 'normal'; not only has this word a general dictionary meaning, and connotation in ordinary intercourse, but it is also used as a technical term in several branches of natural knowledge, and in each the meaning is distinct and different, from that which it bears in other sciences and from that which the uninitiated in any science would attach to it. Hence, when using this word, we must be quite clear as to the precise meaning in which it is used, and avoid the fallacy, only too common, of making it first express a definite fact and then extending its meaning by the connotation which it would have in a different context; it gives an extreme instance of the danger involved in taking a word out of the general vocabulary of our language, and giving it a special technical significance, yet I would not, on that account, advocate its abandonment. It would be impossible to devise another term wholly free from the same danger, unless some entirely meaningless, and probably cacophonous, word were invented; for, so long as the name is derived in any way from existing words and roots, it must from the outset carry with it a more extended meaning than the special one intended to be implied.

A more weighty consideration, perhaps, is the desirability, in certain stages of knowledge, of making use of words which have not a rigid limitation of meaning, but rather of such as have ill-defined limits, capable of extension and modification as the advance of knowledge makes necessary or advisable. The old distinction of normal and reversed faults was made in the early days of our science; in the light of what we now know it is certainly inadequate, but, until our understanding of the processes, causes, and mechanism of the production of faults has advanced much beyond its present state, no approach to a final or complete classification is possible. For these reasons the old terminology may be retained, provided that we distinguish between the technical and untechnical meanings of the words, and remember that, though normal faulting in the former sense may also be normal in the latter in certain regions, it is most definitely not so for others, and not necessarily

so for the world at large. We must also remember that these two classes are not each all of one kind and wholly distinct from the other; it may be, and indeed almost certainly is, the case that both normal and reversed faults comprise more than one group wholly distinct in origin and mode of formation, and that in some cases there is a closer relationship between normal and reversed faults than between them and others of nominally the same class.

There is, however, one very definite difference between normal and reversed faults, in that the former necessitate an increase in the horizontal distance of two points situated on opposite sides of the fault and the latter a decrease. In other words, normal faulting indicates an extension of the country affected by it, and reversed faulting a compression. This distinction has long been recognized, and more than half a century has passed since there appeared a paper by the Rev. J. M. Wilson[1]—whom I revere as my first teacher in geology—on the cause of contortion and faults. In this it was pointed out that the elevation of a tract of country would increase the length of the measurement across the elevated tract, while depression would give rise to a decrease, and calculation was made of the amount of the extension or compression which would be produced in this way. There can be no question that the cause assigned is a true one and that both extension and compression can be produced in this way; but, in the light of our present knowledge of the extent of contortion and faulting, it is evident that the cause is quantitatively inadequate, and that some other must be invoked to account for the amount of change in the original dimensions which is indicated by existing structure. This is not a matter to be dealt with here; but it may be noticed that, although extension of the horizontal dimensions of a faulted region would sufficiently account for the facts of normal faulting, provided that the necessary fractures were in existence, the case of reversed faults is much less simple, for, while they imply a reduction in the horizontal dimensions of the faulted region, it is easily demonstrable that, in many instances, they could not have been produced merely by compression in a horizontal direction. It is true that reversed faulting has been imitated in experiments on a small scale, and produced in those instances by compression; it is equally true that on the scale met with in Nature they might

[1] 'On the Cause of Contortion & Faults' Geol. Mag. 1868, pp. 205–208.

be so produced if there were no such thing as friction; but it is no less certain that when friction along the surface of the fault is taken into consideration it would be impossible for horizontal compression alone to give rise to displacement along a fault-surface, where the hade did not exceed 30° from the vertical, and doubtful if the hade were much less than 45°.

The reasoning is quite simple, clear, and conclusive; there is a certain angle of inclination marking the extreme slope at which one body will rest on another: if the slope is less no movement will take place, if steeper the upper one will slide over the lower down the slope separating the two. This limiting inclination is known as 'the angle of repose,' and varies according to the substance and nature of the surface; for highly finished and well-lubricated metallic surfaces it is only a few degrees, for dressed stone it is not far short of 30°, for an undulating surface, such as is found in even the cleanest-cut fault, the angle would be still higher. Now what is true where the bodies are affected by the vertical force of gravity is equally true of any other force acting in any other direction, the angle being measured from a plane at right angles to the direction of pressure, that is from the vertical, when compression takes place in a horizontal direction. Hence it results that horizontal pressure could not, by itself, give rise to movement along the fault-surface unless the hade were at least 30° from the vertical; where the hade is less, pressure would only lock the two surfaces more closely together, and increase the resistance to movement.

So far the reasoning is clear and conclusive; it is an error, however, to draw, as has been done, the conclusion that reversed faults of lower hade than this limiting angle could not have originated as such, but must have been formed as normal faults, to become apparently reversed through tilting subsequent to their formation. This is one, though not the only, possible deduction from observed facts; for the alternative is open to us that the forces which produced movement along the fault were either vertical, or possessed a considerable vertical component, in the direction in which they acted.

A similar conclusion would result from field-observations of reversed faults. I have myself repeatedly found reversed faults in soft tertiary shales and sandstones, and on the rare occasions when it was possible to find the actual fault-plane unobscured by surface-débris or weathering, it was frequently a clean-cut surface, along

which movement had taken place, without any indication of crushing or deformation of the friable or plastic material on either side. There was no indication of any such resistance to movement as would have resulted from friction at the fault-surface, if the upthrow side had been forced upwards by being thrust against the inclined surface of the fault. On the contrary, the appearance was rather as if the pressure of the overlying on the underlying mass had been temporarily relieved, at the time when the displacement took place. Much the same appearance is frequently presented by normal faults; sometimes there is considerable crushing and deformation close by the fault-surface, such as would reasonably be expected if the movement had been due to the overlying mass sliding, by its own weight, over the inclined surface of the fault; at other times, however, no such appearance is met with, and even soft rock, easily bent or broken, lies on either side of the fault-surface almost as uninjured as if the two sides had been separated from each other when the movement took place.

We must also consider that very large class of faults, sometimes of great vertical throw, in which the fault-surface is either vertical, or so nearly vertical that it is difficult to decide the direction of the hade. In these, and especially where the throw is large, we can hardly attribute their origin simply to extension or compression in a horizontal direction, and we seem compelled to invoke the action of some force acting vertically, or with a very large vertical component, in its direction; and more than that, it must have been one which acted with much greater effect on one side of the fault than on the other, or, possibly, in opposite directions on opposite sides of the fault.

Paradoxical as it may seem, this is by no means physically impossible. Some years ago, when discussing the displacements of the ground which took place along the San Andreas Fault, in connexion with the South Californian earthquake of 1906,[1] I had occasion to refer to the very complicated stresses which are set up in a body subjected to compression, or extension, in one direction, but free to change its form in another, and exhibited to you a model illustrating how a force acting in one direction on the body as a whole might set up stresses, and give rise to displacement, within it, in a wholly different direction. The displacements dealt with on that occasion were of comparatively small amount;

[1] Q. J. G. S. vol. lxv (1909) pp. 1–16.

but it is not possible to place a limit on those which could originate in a similar manner, and it is, at least, not impossible that the movements revealed by faulting may have originated in some analogous way, and that the direction of the forces acting immediately on either side of the fault may have been very different from that of the ultimate influence to which they were due.

Geologists have recognized that to some such cause we must attribute the origin of the fractures which traverse all rocks, frequently with a remarkable parallelism and regularity of direction; but they have not sufficiently recognized that the same cause which gives rise to the fractures may equally be the cause of movement along the surface of the fracture, this movement taking place simultaneously in opposite directions on opposite sides of the fault. Generally faults are too numerous, and form too complicated a system, to allow of such a cause as has been mentioned being recognized in the effect; but all who have had experience of geological survey must have come across instances of faults that can only be detected by close and detailed survey, or by underground workings in mines and quarries. In these cases the disturbance of the even course of the boundary-lines is limited to the immediate neighbourhood of the fault, dying out on either side, just as the displacements in 1906 were localized to the immediate neighbourhood of the San Andreas Fault.

It is no part of my present aim to enter on a discussion of the physics of faulting, the purport of such reference as has been made being to elucidate the meaning, and the limitation of meaning, of the words which we use in a special sense, and to point out that in using the words 'upthrow' and 'downthrow' we must be careful to avoid any implication that the displacement was restricted to one side of the fault; for it may well have taken the form of a simultaneous movement in the same direction, but of different amount, or in opposite directions, upwards on one side and downwards on the other, of the surface of separation.

I have already referred to two classes of technical terms, one of which is a word not used outside some particular department of knowledge, and consequently meaningless to the uninitiated, the other a word in common use, to which a special limited meaning is given when used as a technical term. A third class is that of compound words, in which one or all of the components may be in general use, though the compound is confined to one special branch

of science; and of this a very typical instance is provided by that special form of reversed fault, commonly known as an 'overthrust.' This word is distinctly a technical term special to geology, it is not used as a noun in ordinary speech or writing, nor is it used in any other branch of natural knowledge, yet, unlike the word 'hade,' it is far from meaningless apart from its technical significance, for it is compounded of two common, characteristically English, words, and as such carries with it a whole group of connotations. First, that the rocks now resting upon the surface of separation ought not normally to occupy that position, but have been brought there by displacement from that which they originally occupied; secondly, that the displacement has taken place by a movement of the upper mass over the lower; and, thirdly, that this movement was produced by some cause or force external to the area occupied by the material displaced, which has been thrust as an inert mass, influenced by, but taking no part in the production of, the power by which it was moved.

Doubtless the word was from the outset intended to carry with it the whole of these implications, and so long as it is used only in that extended sense and some other word made use of when a different group of connotations is intended, no objection could be raised; but, if it is to be retained as one of our special technical terms, it is eminently desirable that its meaning should be limited to the first, which expresses a fact, and that it should cease to imply the other two, which are of the nature of a theory of origin. In practice, however, it has generally been used in the extended interpretation, and on this has grown up a mass of controversy as to whether the upper mass was thrust over the lower, or the lower thrust under the upper, as to the direction from which the impulse came, and as to the ultimate cause to which it was due; but the greater part of these controversial writings resolves itself, on critical examination, into mere verbal dialectics, or is inconsistent with some of the fundamental principles of physics.

Taking these points in order, we may first consider that of the direction of movement. In the Scottish Highlands it is quite clear that the upper blocks have moved westwards relative to the lower, in Scandinavia the relative movement of the upper blocks has been eastwards, and in the Alps northwards; but it would be an equally true statement of the facts to say that the movement of the lower masses had been in the opposite direction, and more than this it is impossible to say. Leaving on one side the abstract

disquisitions of pure philosophy on the question of the possibility of there being such a thing as absolute motion, it is certain that it can only be expressed in terms of displacement, relative to some point which has to be accepted as fixed, and this point must necessarily lie outside the body regarded as in movement. From this it results that we cannot determine the direction of displacement of the masses, on either side of the plane of separation, by observations within the region of the displacements; and, as we have no means of reference to some external point, which can be regarded as unaffected, it results that we may only speak with certainty of the relative movements within the region of the overthrust. We are justified in speaking, or writing, for purely descriptive purposes, of an eastward or westward movement of the upper block over the lower, in order to avoid the long periphrases and digressions which would be unavoidable if the true meaning of the observations were always to be expressed in full; but in this case it is desirable to observe uniformity of practice, and always to regard the upper block as having moved relatively to the lower, and especially to remember that the expression is used merely as a convenience in description, not as implying any assertion of displacement or fixity relative to any point outside the area of the overthrust.

Having shown that argument as to the direction of movement is merely discussion of the words in which the facts are to be represented, I come to the question of the direction from which the pressure, to which the movement is attributed, was exerted. This discussion, again, involves a widespread fallacy that pressure can be one-sided; it permeates the great work of Suess, in which we find repeated reference to earth-waves advancing against resistant blocks, and in which the forms of the folds are repeatedly invoked as evidence of the direction from which the pressure came. The deservedly great influence of this work on geological thought has served to emphasize and perpetuate a very natural fallacy, derived from an imperfect interpretation of everyday experience. When a person pushes, for instance, against an unlatched door which yields to the pressure, it is natural for that person to attribute the result to the action of which he is conscious, and to take no account of the inanimate subject of his activities; properly considered, however, both take an equal and opposite part, and the door pushes back in exactly the same degree as the person pushes against it. This is easily recognized when the door is

latched and cannot yield, in this case the resistant pressure of the door is felt and appreciated, yet the same takes place when it is free to move, though the opposing pressure is limited to that necessary to overcome the friction of the hinges and the inertia of the door. Once this limit is reached the door begins to move, and if the pressure exerted by the person is greater than that needed to move the door, at the rate which he wishes to impart, the result may be that he falls forward until he meets the greater resistance of the floor.

A similar fallacy is commonly to be found in the interpretation of experiments on the small scale, intended to illustrate the foldings and faultings of rocks. These generally take the form of a box-shaped receptacle, filled with sand, clay, or other material, the bottom and three sides being solid with each other, while the fourth side can be advanced by means of a screw or other mechanical contrivance. Here we appear, at first sight, to have a case of a solid immovable obstacle and a pressure, combined with movement, exerted from one side in the direction of the fixed obstruction; but when the circumstances are more closely examined, we see that whatever pressure is exerted by the movable side on the contents of the receptacle must be met by an equal and opposite pressure on the nut of the screw, the fulcrum of the lever, or generally on the fixed point from which the purchase is obtained. Looking still farther into the matter, we find that this fixed point must be connected, directly or indirectly, with the body of the receptacle, and so we see that the sides are only nominally fixed or movable, and that the one is drawn in exactly the same degree as the other is pushed; consequently, the pressure on the contents is not from one side towards the opposite one, but in equal amount and opposite directions from each towards the other. When, however, we transfer our consideration from the movements of the sides of the receptacle to the resistance offered by the contents, the conditions become much less simple: in the one case, we have three sides and the bottom all locked together and moving in unison, so that there is no frictional resistance to the forward movement of the contents as a whole; in the other, any displacement of the contents would be resisted by friction against two sides and the bottom of the box, this resistance being apart from that opposed by the contents to deformation, resulting from change in the dimensions of the receptacle. Hence it results that, while the pressure must in every case be equal and opposite, the resistance

to change of form will not be equal in opposite directions, and so the dislocations which result will not be symmetrical with reference to the apparently fixed and movable parts of the receptacle; but this want of symmetry must be attributed to inequality of distribution of the resistance, not to an unsymmetrical disposition of pressure or movement.

In Nature the conditions are further complicated by the fact that the material involved is much less uniform in character throughout the disturbed tract than in the small-scale experiments, and the character of the deformation even less dependent on the direction of the compression, so that if this were in a north-and-south direction the strike of the resulting folds or overthrusts may depart very considerably from the general east-and-west direction. A further complication is introduced by the fact that the rigidly-fixed sides and bottom of the box-shaped receptacle used in the experiment are not repeated in Nature, so that there is a possibility of relief being found laterally or downwards, instead of only upwards; or there may be compression simultaneously exerted in different, possibly widely different, directions.

To unravel all these conditions in detail is beyond our power, in the present state of knowledge, but the important point to be remembered is that we may not deduce from the character of the deformation which rocks have undergone any conclusion of absolute movement of one side of the compressed tract or of the other; all that we can learn, from observation within the disturbed tract, is that the horizontal dimensions have undergone diminution, but whether by movement of one side only or of both, measured relatively to some point outside the tract, cannot be determined. The same reasoning and conclusions apply with equal force to the compression indicated by overthrusts, and the deformations which have, at one time or other, been taken as evidence that the upper mass moved over the lower, or the lower under the upper, are seen to be merely disputation about words, for the structures appealed to are the expression of the resistance offered to deformation by the rocks in which they occur.

As in the case of the direction of movement, it may be a convenience to accept the common usage, incorrect though it be, when referring to the cause to which the displacements are due, so long as the language is understood to be merely descriptive, and so long as we do not allow ourselves, in further following up the train of thought, to be influenced by the words in which the facts of

observation have been presented, rather than by the facts themselves. Yet it would be better that we should abandon this mode of expression altogether, for it is not only fraught with danger to ourselves, and likely to lead to erroneous reasoning, but also it is liable to misunderstanding by ungeological readers who, attaching a different meaning to the words from that which was intended, will conclude that we do not understand the subject with which we are dealing, and so our Philistines be led to scoff.

From the consideration of these two matters which have given rise to controversy, concerned almost entirely with words, by which things that really matter may be described, I now come to one which is a vital one, for it may involve a modification, and in some respects a radical change, in some of the fundamental principles, which have rather been tacitly accepted than definitely proved. In discussions, as in descriptions, of the phenomena or of the origin of these overthrusts, the masses involved have generally been regarded as passive, moving under the influence of external forces in the production of which they took no part. The notion is a natural one, it is the simplest and easiest way of interpreting the facts of observation; but its general acceptance must be very largely attributed to the influence of experiments on a small scale, which have themselves been suggested and directed by the hypothesis which they were intended to illustrate and investigate. In these we have an inert mass, variously composed to imitate, more or less, the rocks of the Earth's crust, and this mass is subjected to deformation by the application of external forces. In this way many of the structures which have been worked out by geological observations in the field were imitated on a small scale in the experiment, and the resemblance was accepted as evidence that the large-scale structures, met with in Nature, were produced, like the small-scale structures of the experiment, by the application of external forces. Difficulties, however, arise when we consider the conditions which are introduced by an increase of dimensions to the scale of Nature; and, when the mechanics of overthrusts are investigated, these difficulties become insuperable.

When one body is pressed against another by any force at right angles to the surface of contact, it may be caused to move by another force acting at right angles to the first, and the magnitude of the second force needful to produce movement bears a definite

ratio to the first, a ratio which depends on the nature of the material and the character of the surface of separation. This ratio is known as the 'coefficient of friction,' and is, numerically, the same as the tangent of the angle of repose. For a flat-dressed surface of stone the coefficient is about three-fifths of the weight of the stone, for a surface such as that of a so-called 'thrust-plane' it would not be less: consequently, to move a block of rocks 5 miles wide would need a pressure equal to that due to the weight of a column, of the same rocks and of the same cross-section, having a height of at least 3 miles, or just about the limit of height of column which average hard rock can bear without crushing.

From these figures it appears that the maximum possible width of the overthrust must be somewhere about 5 miles, if it moved as an inert mass under the influence of some external impulse: for, if the width exceeded this limit, the stresses would be greater than those which rock could bear or transmit, and relief would be found in some other way than by a general displacement along the whole width of the overthrust; but 5 miles is less than half the width of the mass moved in the Highland overthrusts, it is not more than a tenth of that of the Scandinavian, and a still smaller fraction of those which have been deduced in the region of the Alps. From this it might seem to be established that none of these overthrusts could possibly have been produced, and that there must be some error in the observations, or the inferences which have been drawn from them as to structure.

This reasoning, however, is not justifiable. We have again a case very like that which has been mentioned in connexion with what are ordinarily understood as reversed faults, and once more we have to face the alternative that the hypothesis of origin needs correction, not the facts of observation; but, before examining this, it is necessary to refer to one possible means of getting over the difficulty which has been encountered. If we might believe that the coefficient of friction along the surface of the thrust was less than that adopted in the calculation, the width of the blocks which could be moved would be correspondingly increased; but not in this way can sufficient increase be obtained, for even with the most perfectly formed and lubricated surfaces in mechanism the coefficient is not materially less than one-tenth, and the maximum

width of block which could be moved would not be increased beyond about 30 miles. The actual surface along which movement took place being, to say the least, much less perfect than those which give so small a coefficient of friction, the maximum width that could be moved would in any case be less than has, in some instances, been shown by observation in the field. Resistance to movement might, however, be reduced if the downward pressure due to the weight of the upper block were, in some way or other, temporarily relieved, and if this relief were complete there would be no limit to the width of block that could be moved. It is not easy to conceive the means by which this could be brought about, nor is it necessary to consider the possibility, for the existence of mylonites, and other indications, of resistance to movement, given by the deformation and fracture of rock, are eloquent of the resistances which had to be overcome when the existing displacements were brought about. Taking these into consideration, it is evident that the frictional resistance must have been at least as great as is represented by the coefficient made use of, so that the width of 5 miles must be regarded as a maximum rather than a minimum limit of the width of the overthrust which could be moved by pressure from without.

From this we are led to the conclusion that the thrusts did not move simultaneously over the whole of their extent, but partially, first in one part then in another, each separate movement involving an area limited by the strength of the rocks and their power to transmit, or resist the effect of, pressure. Some years ago it might have been said that any supposition of this kind was physically impossible; but at the present day the change of volume which results from an alteration of the molecular grouping of the same chemical elements, expressed geologically as a different mineralogical constitution of rocks having the same chemical composition, or more briefly as a change of mode of the same norm, has opened up at least one means by which the desired effect might be produced. Doubtless the advance of knowledge will open up other possibilities, some of which might be indicated, though I shall not refer to them, as my present purpose is not to deal with things themselves, but with the words in which they are expressed.

One result of the acceptance of any such process as has been suggested is that the origin of overthrusts ceases to have any

resemblance to thrusting in the ordinary sense of the word; the movement would not be like that of a sledge, pushed bodily forward over the ground, but more akin to the crawl of a caterpillar which advances one part of its body at a time, and all parts in succession. A further result is that the motive power would have originated within the area of the overthrust, and, as we cannot conceive of this taking place in the dead rock of the upper block involved, we must put it in the lower one, more directly associated with those lower layers of the crust, in which many imperfectly understood changes are certainly going on, and probably many that are wholly unsuspected at present.

Without entering into advocacy of this hypothesis of origin of overthrusts, the claim must at least be made that it is a possible one, consistent with the facts revealed by observation, and not incompatible with our present knowledge, or ignorance, of the physics of the Earth's crust. If accepted, it follows that the word 'overthrust' suggests something quite different from what actually took place, and that the word 'undercrawl' would more nearly express the manner in which the thing referred to was brought about; yet I have no desire, certainly no intention, to suggest that a well-established term should be abandoned and replaced by one which may be just as misleading, if we define it otherwise than as a reversed fault of very low inclination from the horizontal. So long as the connotation is thus limited, one word is as good as another, and when, wishing to discuss origins and processes of formation, we go beyond this meaning, all words may be equally bad, if we allow collateral meanings of the constituent parts to influence our reasoning.

The theme might be expanded indefinitely, but enough has been said to point the moral, of the danger of loose use of words, and of the necessity of distinguishing clearly between things themselves and the terms in which they are described or mentioned. The lesson is no new one, for the fallacy, of using the same word in more than one sense, must be as old as language and logic; it is so well known that, for over 2000 years logicians have used a special term to describe, and have consistently warned us to avoid, it, yet, old as it is, it is ever new, and the warning needs repeated reiteration, for it is a form of fallacy to which mankind is naturally prone, and almost impossible of avoidance, in the finite

limitation of human intellect, and of the vocabulary at its disposal. It is also one against which geologists must be especially on their guard, for the language which they use is of such modern origin that their special terms have not fully lost the connotation of their origin, and, consequently, the difficulty of differentiating between the special technical significance of the word on the one hand, and the literary, or literal, meaning of its derivation, on the other, is ever present and especially great.

February 23rd, 1921.

Mr. R. D. Oldham, F.R.S., President,
in the Chair.

James McCormick, M.Inst.Mech.E., Chief Inspector of Materials, etc., North-Eastern Railway Dock-Office, Hull, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On *Saccammina carteri* Brady, and the Minute Structure of the Foraminiferal Shell.' By Prof. William Johnson Sollas, M.A., Sc.D., LL.D., F.R.S., F.G.S.

2. 'Notes on the Views of the late Prof. Charles Lapworth with regard to Spiral Movements in Rocks during Elevation or Depression.' By Dr. Theodore Stacey Wilson, B.Sc., F.G.S.

Lantern-slides and microscope-slides were exhibited by Prof. W. J. Sollas, in illustration of his paper; and diagrams and models by Dr. T. Stacey Wilson, in illustration of his paper.

Impressions of moth-wings on stalagmite, from a cave at Burrington Combe (Somerset), were exhibited by Cecil Carus-Wilson, F.R.S.E., F.G.S.

March 9th, 1921.

Mr. R. D. Oldham, F.R.S., President,
in the Chair.

Ralph Walter Segnit, B.A., Balliol College, Oxford; Frederick Murray Trotter, B.Sc., Beehive Inn, Seghill (Northumberland); and Thomas Warde Whitfield, Fern Bank, The Avenue, Trowbridge (Wiltshire), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Surface of the Marls of the Middle Chalk in the Somme Valley and the Neighbouring Districts of Northern France, and the Effect on the Hydrology.' By William Bernard Robinson King, O.B.E., M.A., F.G.S.

2. 'The Bala Country: its Structure and Rock-Succession.' By Miss Gertrude Lilian Elles, M.B.E., D.Sc., F.G.S.

Specimens of fossils were exhibited in illustration of Miss G. L. Elles's paper.

March 23rd, 1921.

Mr. R. D. Oldham, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following communication was read:—

'The Structure of the South-West Highlands of Scotland.' By Edward Battersby Bailey, M.C., B.A., F.R.S.E., F.G.S.

Diagrams and lantern-slides were exhibited by Mr. E. B. Bailey, in illustration of his paper.

Lantern-slides of stone-implements from India were exhibited by Dr. John Coggin Brown, O.B.E., F.G.S.

April 20th, 1921.

Mr. R. D. Oldham, F.R.S., President,
in the Chair.

Edward Beaconsfield Egar de Camps, 121 Spadina Road, Toronto, Ontario (Canada); the Rev. Leo Kevin Clark, Hawkesyard Priory, Rugeley (Staffordshire); Edward Benjamin Howard Cunnington, F.S.A.Scot., 33 Long Street, Devizes; Josef Theodore Erb, 19 Johan van Oldenbarneveltlaan, The Hague; William Green, South Parade, Northallerton (Yorkshire); Hamlin Brooks Hatch, St. John's (Newfoundland); Robert George Spencer Hudson, B.Sc., 43 Lady Margaret Road, N.W. 5; Richard Moroni Kendrick, 75 Wool Exchange, E.C. 2; William Francis Porter McLintock, D.Sc., Curator of the Museum of Practical Geology, 28 Jermyn Street, S.W. 1; Bert Perrot, Brynclydach, Neath (Glamorgan); Harry Mackenzie Ridge, Llanfoist, 22 Crescent Road, Crouch End, N. 8; James Stanworth, 66 Peart Street, Burnley; Ronald Hawkesby Thomas, M.C., B.A., New Oxford & Cambridge Club, S.W. 1; and Frederic Louis Watkins, St. Maur, Ventnor (Isle of Wight) were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Geological Sections through the Andes of Peru and Bolivia: III—From Callao to the River Perene.' By James Archibald Douglas, M.A., B.Sc., F.G.S.

2. 'The Valentian Series.' By Prof. Owen Thomas Jones, M.A., D.Sc., F.G.S.

May 4th, 1921.

Mr. R. D. OLDHAM, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'An *Ottokaria*-like Plant from South Africa.' By Hugh Hamshaw Thomas, M.B.E., M.A., F.G.S.

2. 'On *Nummulospermum*, gen. nov., the probable Megasporangium of *Glossopteris*.' By A. B. Walkom, D.Sc. (Communicated by Prof. A. C. Seward, Sc.D., F.R.S., F.G.S.)

3. 'The Evolution of Certain Liassic Gastropods, with special reference to their Use in Stratigraphy.' By Miss Agnes Irene McDonald, B.Sc., and Arthur Elijah Trueman, D.Sc., F.G.S.

May 25th, 1921.

Mr. R. D. OLDHAM, F.R.S., President,
in the Chair.

Thomas Henderson, M.C., Flight-Lieut. R.A.F., 15 Syon Street, Tynemouth (Northumberland); Michael Anthony Hogan, B.E., M.Sc., City & Guilds (Engineering) College, South Kensington, S.W. 7; Thomas Brynmawr Jones, Derwydd, Brynmawr (Breconshire); William John Pugh, Professor of Geology in the University College of Wales, Aberystwyth; Lancelot Elce Wilson, c/o Mrs. Porter, St. Mary's, Ely (Cambridgeshire); and Robert Ralph Williams, The Moorlands, Trealaw, Rhondda (Glamorgan), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'On the Junction of Gault and Lower Greensand near Leighton Buzzard (Bedfordshire).' By George William Lamplugh, F.R.S., V.P.G.S.

Specimens and diagrams were exhibited by Mr. Lamplugh, in illustration of his paper.

June 8th, 1921.

Mr. R. D. Oldham, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

Dr. William Fraser Hume opened a discussion on the Relations of the Northern Red Sea and its Associated Gulf-Areas to the 'Rift' Theory, in the following words:—

(1) The areas specially considered are the northern portion of the Red Sea and a region to which the name of 'Clysmic Gulf' has been given. The Clysmic Gulf (from Clysma, the Roman name for Suez) is defined as the district bordering the Gulf, and lying between the (largely) fault-bounded ranges of Egypt and Sinai on the west and the east respectively which dominate this depressed area. Within its borders Miocene deposits are of wide distribution; beyond them, these are notably absent. The folds within this region are from north-west to south-east, outside it their trend is frequently almost at right angles.

(2) A line prolonging the direction of the western coast of the Gulf of Akaba to the shores of Egypt divides the Clysmic Gulf from the Red Sea, the former being occupied by the shallow Gulf of Suez and disturbed lowlands, while south-east of the dividing-line is the Red Sea, with its great depths and its narrow coast-line.

(3) The Clysmic-Gulf area is one of complicated fold-and-fracture effects, while in that of the Red Sea only fold effects have been observed.

From a study of the facts known, it is concluded that:—

(4) The whole region under consideration underwent extremely slow submergence, the negative movements continuing from early Jurassic to late Cretaceous times.

(5) This was succeeded by one of a positive nature, the actual emergence of the new land taking place near the close of the Eocene Period. It is suggested that the area was occupied by an anticline or anticlinorium plunging northwards in the Clysmic-Gulf region, and that it was subject first to marine and then to subaërial erosion. This formed part of the continent on which grew the trees of the Petrified Forest, and on which wandered animals such as the *Arsinoitherium* and the earliest elephants. This continental period was most marked during late Eocene and early Miocene times, and the area dealt with here appears to have become one of very varied ridge and depression.

(6) The whole region thus dissected was invaded by the ancient Mediterranean; the slow advance southwards occupied the main portion of the Miocene Period, and probably extended well into the Pliocene. The pre-existing ridges became coral-reef centres: the intervening depressions were filled up, first by land-derived

deposits (such as conglomerates and clays), and then by lagoon formations (gypsum and salt). The earliest of these formations appear to have been of Schlier (Middle Miocene) age.

(7) The sequence of events from Middle Pliocene times onwards is difficult to unravel. The whole region of the Clysmic Gulf became folded and fractured to a remarkable extent, there being certain underlying elements of order discernible. There is strong faulting at the borders with the igneous hills, and fold-ranges are well marked, these being of asymmetrical anticline type. It is suggested that compression of the area, with uplift of portions of it, offers the best solution for the facts observed. It seems difficult to conceive that dislocation so marked, spread over so wide an area, could arise under rift formation as defined by Prof. J. W. Gregory. It seems equally difficult to ascribe the whole of the surface-differences to erosion alone. It will be readily understood that no simple solution of the problem can be offered on the evidence at present available, especially in view of the fact that no important faulting has been noted on the western borders of the Red Sea.

(8) The same reserve must be exercised with regard to the very interesting eroded trough-fault valleys, which the writer formerly regarded as of rift origin.

(9) A suggestion is made that the portion of the Nile Valley about lat. 26° N., where faulting is most conspicuous, may have been initiated by erosion of a sharp anticlinal fold due to the compression of almost horizontal strata. Sharp folds exist in the desert east of the Nile, but their origin is at present doubtful.

Discussion.

The President said that it had been customary of late years to devote at least one meeting in the Session to a lecture on some subject of interest to geologists, or to a discussion of one of the larger and more speculative problems of geology. The subject selected for discussion that evening might be briefly defined: there was in Central Africa a well-known surface-feature, for which Prof. J. W. Gregory had popularized the name of the Great Rift Valley; there was also, in Southern Syria, a similar surface-feature, occupied in its northern part by the Jordan Valley, and continued as a surface-depression to the Gulf of Akaba. According to one school of thought, these two surface-features were not only of similar genesis, but formed the extremities of a continuous surface-feature, intimately related in origin to the tectonics of the surface-rocks, called the African Rift Valley, of which the Red Sea was regarded as an integral and important section. According to another school, no such continuity is recognized, and the origin of the Red Sea is attributed to causes other than those which gave rise to the rift-valleys of Africa proper and of Palestine. Dr. Hume had had a large personal experience of the geology of the Red-Sea region, and his presence in England afforded a useful opportunity of raising a discussion of this important and interesting problem.

Col. H. G. Lyons expressed his great interest in the information that Dr. Hume had laid before the Society, which made the structure of this part of North-Eastern Africa much clearer. He agreed that former assumptions of the rift character of the Nile Valley were not tenable, and that the Gulf of Suez, too, could not be strictly described as a rift-valley. For the Red Sea, he asked whether more information had been collected of late as to the structure of the eastern shore, to show whether it was as free from fracture-lines as the western was, according to Dr. Hume's account.

Prof. J. W. Gregory, in a letter sent as a contribution to the discussion, remarked that the agreements between Dr. Hume's views and his own were more essential than the differences. The sequence of events stated by Dr. Hume for the Clysmic Gulf is similar to that which he had adopted for the Rift Valley as a whole—including Jurassic subsidences due to the Mesozoic deformation of the crust, an Eocene land over the Red Sea, subsidence of the Rift-Valley trough in the Oligocene, renewed and extended especially in the late Pliocene Period. The Gulf of Suez is not typical of the Rift Valley, as its lines there intersect those of the Levant, and as the rocks traversed are mostly young stratified deposits.

The main difference between the writer's interpretation and that stated by Dr. Hume is the relative importance of fold and fault. The importance of the faults is indicated by Dr. Hume's remark that

'the (largely) fault-bounded ranges dominate this depressed area,'

and by his statements (Geol. Mag. 1910) regarding the dome over the Clysmic Gulf :—

'I can conceive of no erosive agent which would break across this great earth-feature without the intervention of fracture,' [and that] 'faulting, and faulting alone, can explain the phenomena.'

These conclusions are supported by the recent statements in bulletins by the Geological Survey of Egypt that faulting was

'the controlling factor in the formation of the shore line of the Gulf' [and in] 'determining the present position of the Gulf of Suez.'

The attribution of the Red-Sea section of the Rift Valley to folds appears to be due to the use of the term 'fold' for movements which the writer regards as faults. The Geological Survey of Egypt has recently explained its use of the word 'fold' by a diagram[1] which identifies a steep, plane, slickensided surface as a fold. The writer regards the movement shown by this diagram as a fault, so that the difference is a question of terms. He found it impossible, in view of the post-Eocene faults with fault-breccias beside the Gulf of Aden and the maps of the Egyptian Geological Survey at

[1] Petrol. Res. Bull. No. 6, 1920, sketch before p. 1.

the other end of the Red Sea, to accept the view that on the Red Sea only fold-effects have been observed. He agreed that the Lower Nile Valley is not a Rift Valley, its structure being the antithesis to that of the Red-Sea trough.

With regard to the length of the Rift Valley, he referred to the explanation in his forthcoming book 'The Rift-Valleys & Geology of East Africa' (briefly stated in Geogr. Journ. vol. lvi, p. 38), representing it as due to worldwide mid-Kainozoic earth-movements, and to its position between the mountain-forming movements in Europe and Africa which were northward, and the simultaneous Asiatic movements which were southward. Its great length is due to the continental scale of the accompanying movements, and seems no more inconsistent with its formation by tension than the equal length of the contemporary fold-mountain system is inconsistent with their formation by compression.

Dr. J. W. Evans thought that the structure of the Akaba and Clysmic gulfs would prove very different, the latter being probably the same as that of the Dead-Sea depression. He enquired whether the faults shown in Dr. Blanckenhorn's map near Suakim, parallel to the coast in that neighbourhood, and approximately parallel to the Gulf of Akaba (though not in the same line), were authentic, and, if so, whether they had a downthrow towards the sea. The deep depression in the north of the Red Sea was sharply defined, both on the north and on the south, and suggested a subsidence. The existence of a 'graben' seemed to point to a state of tension, when it was found, but did not imply the existence of a rift as wide as the sunken area. The speaker looked forward to the production by the Egyptian Survey of further evidence on this most important question.

Mr. G. W. Lamplugh remarked that the 'rift-valley' hypothesis raised the wider question as to the supposed prevalence in many parts of the world of large-scale surface-features produced directly by comparatively recent faulting. The geological record showed that the local development of troughs of depression had been frequent throughout the accumulation of the stratified rocks; and the resultant synclines were often faulted longitudinally at the margins, as well as within. But the field-evidence generally implied that the subsidences had been gradual, and the faults of slow growth. Secondary 'fault-controlled' features, due to selective denudation, were common enough both in valleys and on high ground, but new original fault-scarps were difficult to find: he had not yet himself seen a single convincing example, though he had seen several to which this origin was ascribed. He knew no case of the trunk-drainage of a land-area having been revolutionized by the uprise of a fault-block athwart it; and this seemed to imply that the surface-effects of faults for a long time past had never been rapid enough to overcome the ordinary course of weathering and erosion. The conception of the 'rift-valley' had always been attractively simple, and there may be features on the Earth to which the conception will apply absolutely; but the

researches of Dr. Hume and his colleagues have shown that we must now look elsewhere than in Egypt.

The President said that the interesting and instructive discussion had left two doubts in his mind still unsatisfied. One was whether two distinct problems, the origin of rift-valleys and the origin of the Red-Sea depression, had not been confused. The magnitude of the Red-Sea depression was of so different an order from that of the African rift-valleys, that any similar rifting, which may have taken place, would be of subsidiary importance in determining the position and form of the Red Sea. The other doubt was as to the existence of anything which could properly be called the Great Rift-Valley. There was in Africa a belt of country in which the surface-form known as a 'rift-valley' was of fairly frequent occurrence; but it seemed to him that there was insufficient evidence of continuity between them, or of the existence of one continuous rift-valley. It appeared more likely that further investigation would prove the independence of the individual depressions, which should rather be regarded as separate members of a continuous range or series.

Dr. W. F. Hume, in reply, thanked Col. Lyons for his remarks, and pointed out that Dr. Blanckenhorn had never himself visited the Red-Sea region, the faults inserted having no basis of observation. With regret it had to be stated that Dr. Blanckenhorn was frequently incorrect in regard to the existence of faults in Egypt. He had bordered the Fayûm with faults and then removed them, shown an important one at Moghara Oasis which could not be confirmed, and finally bordered the Red Sea with faults where proof of their existence was absolutely wanting.

Prof. Gregory was certainly justified in stating that the actual diagram exhibited was a true fault; but, if continued, it passed into a monoclinal fold. The point did not affect the main issue, as the section was within the area of admitted fracture.

Instead of assuming all the depressions discussed as part of a great rift system, each had to be considered on its merits. The parallelism of the Red-Sea borders could be explained as due to erosion of a broad fold, and, apart from the apparent absence of faulting on the large scale along its borders, the breadth of that sea was such as to make it most difficult to conceive it as a tension-crack. In the Clysmic-Gulf area, which was narrower, and lying between hill-masses of granite or limestones, folding and fracture were intensely marked, but might well be due to compression. The features on which special attention would have to be concentrated in connexion with rift questions were the relatively narrow valleys of the Jordan, the Dead-Sea depression, and those of South-Eastern Sinai, for which no simple erosion theory seemed satisfactory. They were undoubtedly, like the Clysmic Gulf, fault-guided or fault-controlled depressions.

The speaker, as a result of his own studies, agreed with Mr. Lamplugh that a dogmatic assertion of rifts at this stage

might give a bias to younger geologists which might cloud the truth, this being one of Dr. John Ball's objections to Prof. Gregory's original paper.

Dr. Hume also was glad to note the President's remarks, and thought that the idea of 'tension regions,' as advocated by Dr. Evans on this occasion, was one to be approached with great caution, as it required very full experimental evidence.

June 22nd, 1921.

Mr. R. D. Oldham, F.R.S., President,
in the Chair.

William Sawney Bisat, 1 Selwyn Avenue, North Ferriby, Hull; Arthur William Blanford, A.R.S.M., Kolar Goldfield Prospecting Department, c/o Grindlay & Co., Bombay; Charles John Philip Cave, J.P., M.A., F.R.A.S., Stoner Hill, Petersfield (Hampshire); and John Jerom Hartley, M.Eng., B.Sc., M.Inst.C.E., Church Walk, Ambleside (Westmorland), were elected Fellows of the Society.

The List of Donations to the Library was read.

The Names of certain Fellows of the Society were read out for the first time, in conformity with the Bye Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the arrears of their Annual Contributions.

The following communications were read:—

1. 'The Jurassic of New Zealand.' By Charles Taylor Trechmann, D.Sc., F.G.S. With an Appendix on Ammonites from New Zealand. By Leonard Frank Spath, M.Sc., F.G.S.

2. 'The Norite of Sierra Leone.' By Frank Dixey, M.Sc., F.G.S., Government Geologist of Sierra Leone.

Specimens and lantern-slides were exhibited in illustration of the papers by Dr. C. T. Trechmann and Mr. F. Dixey.

THE

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1. *A* SEASONAL VARIATION *in the* FREQUENCY *of* EARTHQUAKES. *(Second Communication.)* By RICHARD DIXON OLDHAM, F.R.S., F.G.S. (Read November 17th, 1920.)

IN an earlier communication to this Society[1] it was shown that there is a slight excess of frequency of earthquakes, above the general average, during the day in summer and during the night in winter. It was also pointed out that this might possibly be a result of the unequal range of variation of the gravitational stresses set up by the sun, and, if so, might be expressed in the form that there was an excess of frequency of earthquakes during that half of the day which contained the upper meridian passage when the declination of the stress-producing body and the latitude of the place were of the same name, and during the half which contained the lower meridian passage when they were different. If this were the true statement of the variation, a similar effect ought to be noticeable, and of greater amplitude, when the record was tabulated by lunar time and declination. Such was actually found to be the case in the only record already tabulated in a form permitting the application of the test, but the number of shocks contained in this record was not large enough to give more than very small weight to the numerical values obtained from it.

Since then I have been able, with the assistance of the Government grant of the Royal Society, to prepare a fresh tabulation of the records of Italian earthquakes by lunar, as well as by solar, hour-angle and declination. The period chosen was the 19-year lunar cycle covering the years 1896 to 1914, this being the period for

[1] Q. J. G. S. vol. lxxiv (1918–19) pp. 99–104.

which the most complete record was available in England; and the tabulation was confined to those earthquakes which originated within the limits of Italy proper, excluding all those which originated in the Alpine districts, or outside the limits, of Italian territory. The number of earthquakes dealt with was 6607, and an abstract tabulation by quarter days is appended to this paper.

Taking the day and night halves of the solar and lunar day, the number of shocks recorded in each, and the ratio of these numbers to each other, come out as in the tabular statement below.

	Solar.				Lunar.			
	Shocks.		*Ratio.*		*Shocks.*		*Ratio.*	
	Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.
Declination North	1440	2006	836	1164	1694	1667	1008	992
Whole Record	2733	3874	827	1173	3269	3338	989	1011
Declination South	1293	1868	818	1182	1575	1671	970	1030

From these figures it appears that the same difference in the ratio of day to night shocks, when the declination is north or south, as compared with the general average ratio of the whole period, is in the same direction in both solar and lunar tabulations, and that the magnitude of the variation in the latter is about double that found in the former, the actual ratio being 9 : 19 in the solar and lunar tabulations respectively. As the ratio of magnitude of the corresponding gravitational stresses is about 9 : 21, or practically the same as that of the variation in frequency, the figures may be taken as confirmatory of, and as giving a considerable degree of probability to, the interpretation suggested in the earlier communication.

Distribution of Earthquakes in Italy, 1896–1914.

[Hour-angles are reckoned from the lower meridian passage.]

Hour-Angles.	0–6.	6–12.	12–18.	18–24.
Solar :				
Declination North	1150	710	730	856
Declination South	1032	723	570	836
Whole Record	2182	1433	1300	1692
Lunar :				
Declination North	790	824	870	877
Declination South	835	733	842	836
Whole Record	1625	1557	1712	1713

[The distribution of shocks by hours is not tabulated here, but was extracted and submitted to the usual process of harmonic analysis. The solar record gave for the diurnal and semidiurnal periods the formula

$$F=1+{\cdot}30 \sin (t+58^\circ\ 30')+{\cdot}10 \sin (t+12^\circ),$$

which is very close to the formula (1) on p. 103 (*op. cit.*), and, as in that case, almost completely covers the diurnal variation in frequency. The lunar record, treated similarly, gives the formula

$$F=1+{\cdot}05 \sin (t+151^\circ\ 30')+{\cdot}015 \sin (2t+168^\circ).$$

Here the epochs of maximum frequency are very different from those of the solar record, but the coefficients, which do not, even in the case of the solar record, exceed the expectancy, are also reduced to an insignificant magnitude; the real meaning, therefore, of the formula is that there is no indication of either diurnal or semidiurnal variation of frequency which can be correlated with the hour-angle of the moon. Hence we may conclude that the variation in frequency of earthquakes at different times of the day, which is conspicuous and consistent, so far as Italy and the last quarter-century are concerned, cannot be attributed in any appreciable degree to the gravitational stresses set up by the sun.

This leaves the third term of the formula (5) as the only one which can be attributed to this cause.]

2. *The* ARCTIC FLORA *of the* CAM VALLEY *at* BARNWELL, CAMBRIDGE.

By Miss MARJORIE ELIZABETH JANE CHANDLER, Harkness Scholar, Newnham College, Cambridge. (Communicated by Prof. J. E. MARR, Sc.D., F.R.S., F.G.S.
Read November 3rd, 1920.)

A SECTION in Pleistocene gravels at Barnwell, Cambridge, was described by Prof. Marr & Miss E. W. Gardner in 1916.[1] They drew attention to the occurrence there of peat-seams yielding definite plant-remains, which were submitted to the late Clement Reid for identification. His preliminary report, showing the Arctic nature of the flora, was incorporated by Prof. Marr in a paper read before the Geological Society[2]; but, unfortunately, death prevented Mr. Reid from undertaking the full examination of the beds which he had, no doubt, intended to make.

I lately had the opportunity of investigating the Barnwell pit, and the examination of fresh material revealed the existence of a far larger fossil flora than was suspected originally. The records of such Arctic floras in low latitudes are few, and in the present instance a number of plants identified had not been recognized previously in the fossil state. It was thought desirable, therefore, that the results of this fuller study should be placed on record, in order that they might be available to other workers in the same field.

Owing to the great kindness of Mrs. E. M. Reid, I was able to use the unique collection of recent seeds made by Mr. Reid in his lifetime, and that collection (referred to as the Reid Collection throughout this paper) was the standard for all my systematic work.

As the stratigraphical details were dealt with in 1916,[1] no full account of the beds is given here, but the accompanying section, drawn to scale, should serve to make clear the respective positions of the different seams examined (fig. 1, pp. 6–7).

These seams were composed of broken and matted fragments of stems, of leaves and of bark, together with fruits and seeds. In some the peat was coarse, consisting largely of thick twigs of willow and birch, as in Seam X. In others the vegetable remains were finer, and leaves, which were often much worn, predominated, as in the l o w e s t s e a m or in the m i d d l e s e a m a b o v e t h e T r a m w a y. Yet others, for example the f o u r

[1] Geol. Mag. 1916, p. 339.
[2] Q. J. G. S. vol. lxxv (1919–20) p. 204.

parallel seams, were poor in leaves and twigs, but very rich in small seeds and in tiny black galls.

To what cause such differences were due is uncertain. If there were a seasonal cause, no definite seasonal sequence could be made out, owing to the irregular mode of occurrence of the seams. Perhaps, however, the variation merely depended on the capacity of the water for carrying a load at the time of formation of any particular seam, and this view was supported by the fact that a thick peat-layer, which occupied a definite stream-channel at the eastern end of the section, was composed almost wholly of the coarsest and heaviest vegetable remains; in it twigs were very abundant, but seeds and leaves were scarce. However these variations were caused, it was clear that the Barnwell seams represented accumulations of vegetable débris washed from various parts of the river-basin; there was no indication that the peat was in the position of growth.

If we judge by the botanical evidence, climatic and ecological conditions remained the same in the Cam basin throughout the accumulation of the seams. Hence the plants obtained from each horizon may be regarded as representing one and the same flora; but, lest future work should give a new significance to such differences as existed between the floras of individual seams, these floras are enumerated separately in an appendix to this paper.

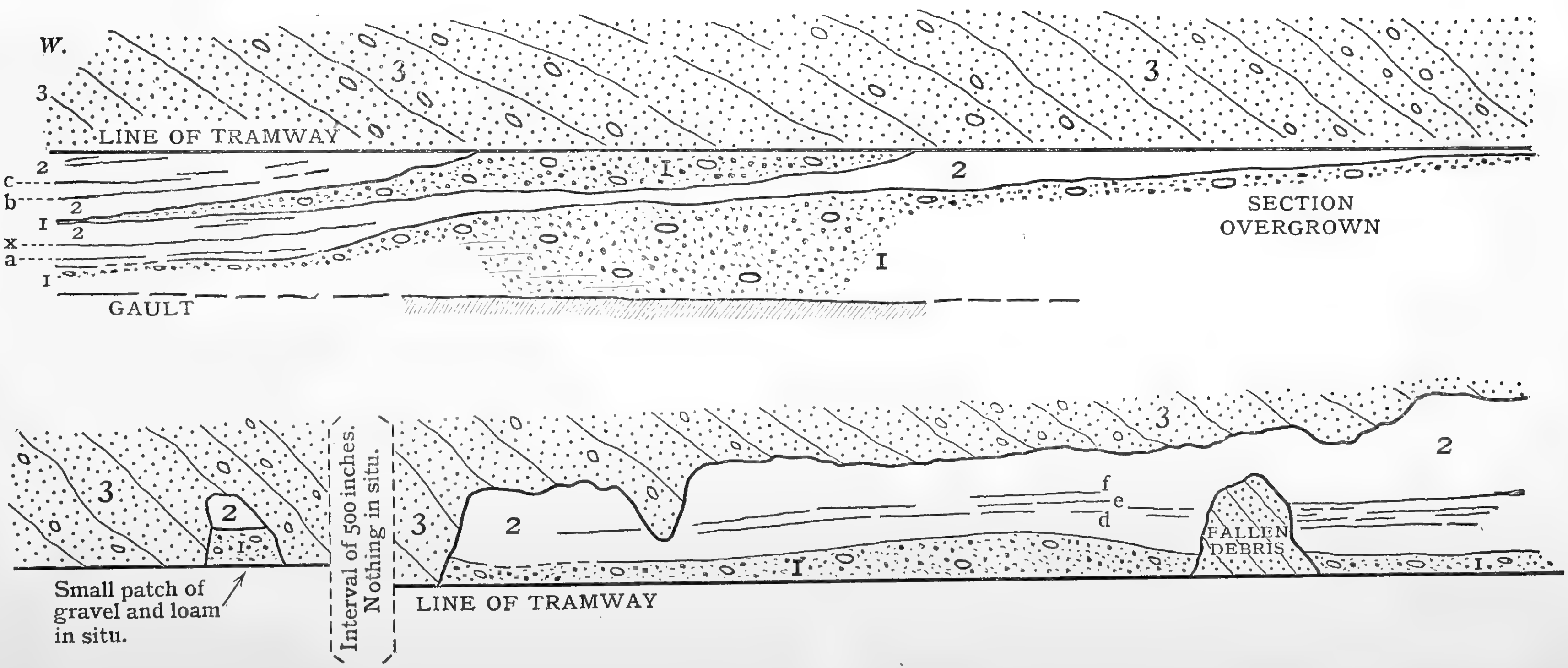
The plants enumerated on pp. 8–10, including those identified by Mr. Reid,[1] constitute the Barnwell Flora up to date.

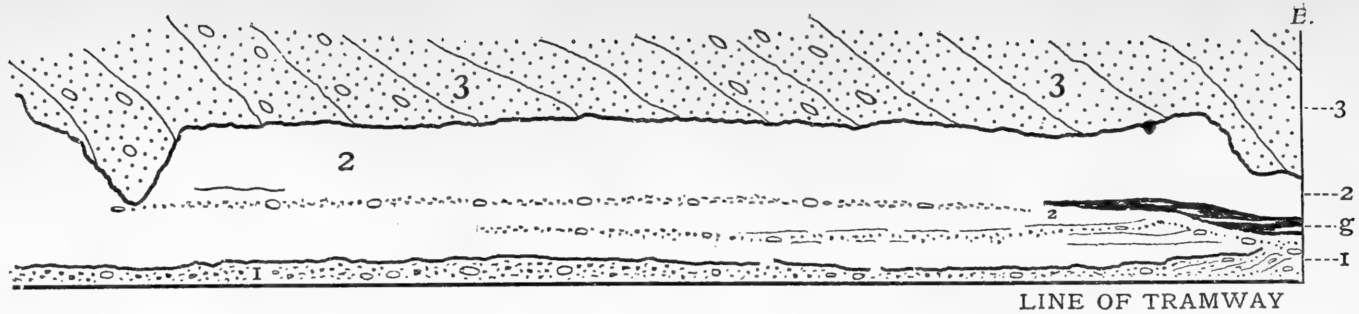
Generally speaking, the species to which the fossils belonged were determined, but occasionally a plant could be referred to its genus only, either because of the inevitable incompleteness of the Reid Collection, or on account of the bad state of preservation of the specimens. Plants believed to be unrecorded previously in the fossil state were noted, but the literature of the subject is so scattered that records of some fossils may possibly have been overlooked.

A careful study of the plant-lists showed that the flora consisted of several groups of plants which were dependent for their existence upon special climatic and ecological factors; with the view of obtaining an idea of the flora, as a whole, these plant-groups, rather than the individual species themselves, are described.

[1] J. E. Marr, Q. J. G. S. vol. lxxv (1919–20) p. 226.

Fig. 1.—*Section in the northern face of the brickpit, Barnwell Station, as exposed in June 1920.*





Length represented in section = 1500 inches. Scales, vertical & horizontal = 1 : 80.

1 = Gravel *in situ*; 2 = Loam or sand yielding peat; 3 = Disturbed gravel, not *in situ*.

Peat-seams are represented by heavy lines in the loam. Seams were too numerous for all that were actually present to be shown on so small a scale.

a = Lowest seam below the Tramway.
b = Seam X below the Tramway.
c = Four parallel seams below the Tramway.
d = Lowest seam above the Tramway.
e = Middle seam above the Tramway.
f = Top seam above the Tramway.
Seams from which material was examined by the Author.

x = Seam from which material was examined by Clement Reid, and subsequently by the Author.

g = Small channel, clearly marked out by a peaty layer, which yielded no leaves, few seeds, but abundant twigs and bits of bark.

[The letters in the central column denote the relative abundance of different species in the deposit. C=very common, c=common, f=frequent, s=scarce. Actual numbers are given where one or two specimens only were found. Where the word 'exotic' occurs in the third column, it signifies that the plant in question is not indigenous in Britain at the present day. L. stands for Linnæus throughout.]

Thalictrum alpinum L.	C	Recorded also from the Lea Valley in late Glacial beds.
Thalictrum minus L.	s	
Batrachium hederaceus L.	c	Recorded from the Lea Valley.
Batrachium spp.	...	
Ranunculus aconitifolius L.	C	Exotic. Not previously recorded fossil. Doubtfully identified with *R. amplexicaulis* L. by Mr. Reid,[1] but the examination of fresh material showed that it really agreed with *R. aconitifolius*.
Ranunculus Flammula L.	s	Recorded doubtfully from the Lea Valley.
Ranunculus Lingua L.	s	Recorded from the Lea Valley.
Ranunculus repens L.	s	Recorded from the Lea Valley.
Ranunculus bulbosus L.	s	
Papaver alpinum L.	1	Not previously recorded fossil.
Fumaria sp.?	...	
Draba incana L.	c	Represented by carpels. Recorded from the Lea Valley.
Cochlearia officinalis L.	2	Represented by carpels. A *Cochlearia* was recorded from the Lea Valley, but the species was undetermined.
Helianthemum sp.	1	
Viola palustris L.	2	Recorded from the Lea Valley.
Silene cælata Reid	f	An extinct plant. Recorded from the Lea Valley.
Lychnis sp.	...	Exotic.
Arenaria sedoides L.	f	Not previously recorded fossil.
Arenaria biflora L.	1	Exotic. Not previously recorded fossil.
Arenaria gothica Fries	1	Not previously recorded fossil. In Britain now found only on Ingleborough.
Arenaria sp.	2	
Stellaria sp.?	...	
Caryophyllaceæ	1	Seed.
Geranium sp. x	C	
Geranium sp. y	1	Carpel. Exotic.
Linum Præcursor Reid	c	Recorded from the Lea Valley. An extinct plant.
Potentilla Anserina L.	c	Recorded from the Lea Valley.
Potentilla argentea L.	1	
Potentilla alpestris Hall	1	Not previously recorded fossil.
Potentilla fruticosa L.	1	Not previously recorded fossil.
Potentilla Tormentilla Neck.	c	=*Potentilla erecta* L. Recorded from the Lea Valley.
Rubus sp.	1	
Dryas octopetala L.	s	Leaves.

[1] J. E. Marr, *loc. cit.*

Myriophyllum spicatum L.	f	Recorded from the Lea Valley.
Hippuris vulgaris L.	c	
Saxifraga oppositifolia L.	f	Leaves, fruits, and shoots. Recorded fossil on the Continent, but not in this country.
Scabiosa sp.	1	Exotic.
Campanula sp.	1	
Vaccinium uliginosum L.	s	Leaves.
Gentiana cruciata L.	1	Exotic.
Menyanthes trifoliata L.	C	Recorded from the Lea Valley.
Bartsia sp.	1	Nearest to *B. alpina*, but only half as large as that species.
Ajuga reptans L.	1	
Primula scotica Hook.	1	Not previously recorded fossil.
Primula sp.	1	Exotic.
Armeria arctica Wallr.	C	Recorded from the Lea Valley.
Rumex maritimus L.	1	
Polygonum viviparum L.	f	Recorded fossil from Saxony, but not previously from this country.
Salix cinerea L.	1	Leaf.
Salix repens L.	C	Leaves. Recorded from the Lea Valley.
Salix Arbuscula Fries	c	Leaves.
Salix Lapponum L.	c	Leaves. Recorded from the Lea Valley.
Salix herbacea L.	2	Leaves. Recorded from the Lea Valley.
Salix Polaris Wahl.	2	Leaves. Exotic.
Salix reticulata L.	2	Leaves. Recorded from the Lea Valley.
Betula nana L.	C	Fruits, male catkins, and leaves abundant. Recorded from the Lea Valley.
Carpinus Betulus L.	1	Recorded from the Lea Valley.
Sparganium simplex Hudson	1	
Sparganium minimum Fries	1	Recorded from the Lea Valley.
Potamogeton heterophyllus Schr.	c	
Potamogeton Zizii Roth	s	Not previously recorded fossil.
Potamogeton obtusifolius M. & K.	f	Recorded from the Lea Valley.
Potamogeton filiformis Nolte	C	Recorded fossil from Denmark.
Potamogeton densus L.	f	
Potamogeton spp.	...	
Zannichellia pedunculata Reich.	f	Recorded from the Lea Valley.
Naias marina, var. *intermedia* A. Braun.	1	Identification kindly confirmed by Dr. Rendle.
Eleocharis palustris R. & S.	c	Recorded from the Lea Valley.
Eleocharis uniglumis Link	f	
Rhynchospora sp.?	1	
Scirpus lacustris L. (?)	1	Recorded from the Lea Valley.
Eriophorum polystachion L.	1	Not previously recorded fossil.
Eriophorum latifolium Hoppe	1	
Carex capitata L.	c	Exotic. Not previously recorded fossil.
Carex arenaria L. (?)	2	
Carex divisa Hudson	1	
Carex vulpina L. (?)	1	
Carex lagopina Wahl.	s	Not previously recorded fossil.
Carex Goodenovii Gay	C	This species was at first identified with *C. incurva* Lightfoot by Mr. Reid,[1] but the examination of more material has since proved it to be *C. Goodenovii*.

[1] J. E. Marr, *loc. cit.*

Carex atrata L. (?)	s	Not previously recorded fossil.
Carex ustulata Wahl.	f	
Carex capillaris L.	s	
Carex glauca Scop.?	s	Badly preserved.
Carex flava L.	1	
Carex rostrata Stokes	f	Recorded from the Lea Valley.
Carex spp.	C	These were among the most characteristic fossils of the deposit. They are well represented in all northern and Arctic floras.
Isoëtes lacustris L.	s	Recorded from the Lea Valley.
Selaginella spinulosa A. Braun.	f	Macrospores. Not previously recorded fossil from this country,
Chara sp.	C	Nucules. Recorded from the Lea valley.

(*a*) The Arctic-Alpine Group.

There are many Barnwell fossils the modern representatives of which appear both in Temperate and in Arctic regions. When found in the Temperate Zone they occur only on upland moors and on mountain-slopes, where some are plants of wide distribution, growing throughout extensive elevated tracts, while others are of a more extreme type found only in limited areas at considerable altitudes. These extreme forms are members of the scanty flora of the mountain-top detritus, or of the open plant-associations of the higher slopes; generally, they form cushions and tufts upon exposed rock-surfaces. Yet others occupy the more sheltered damp ledges on mountain-summits, or flourish in ravines or along mountain stream-banks. When growing in Arctic regions, these same plants are no longer confined to Alpine situations, but flourish at sea-level. In many cases they extend far beyond the Arctic Circle, and some of them are counted among the most widely distributed of Arctic species, occurring in all Arctic countries.

These plants form a striking element in the Barnwell Flora, since they constitute 42 per cent. of the whole, having regard only to those fossils in which the specific, as well as the generic, determination was made. They are as follows:—

Thalictrum alpinum L.
Ranunculus aconitifolius L.
Papaver alpinum L.
Draba incana L.
Cochlearia officinalis L.
Arenaria sedoides L.
Arenaria biflora L.
Potentilla alpestris Hall.
Potentilla fruticosa L.
Dryas octopetala L.
Saxifraga oppositifolia L.
Vaccinium uliginosum L.
Primula scotica Hook.
Armeria arctica Wallr.
Polygonum viviparum L
Salix Arbuscula Fries.
Salix Lapponum L.
Salix herbacea L.
Salix Polaris Wahl.
Salix reticulata L.
Betula nana L.
Potamogeton filiformis Nolte.
Eriophorum polystachion L.
Carex capitata L.
Carex lagopina Wahl.
Carex atrata L. (?).
Carex ustulata Wahl.
Carex capillaris L.
Selaginella spinulosa A. Braun
Isoëtes lacustris L.

(*b*) The Group of Plants of Wider Distribution.

In addition to the markedly Arctic or Alpine plants of the preceding group, other fossils were identified with species which have a wider geographical distribution, although their range is more limited towards the north. In the Temperate Zone, these plants are common in lowland situations, but they also flourish on higher ground. The plants identified include species which now characterize such varied habitats as water, marsh, meadow, and heath. They are as follows:—

Ranunculus Flammula L.
Ranunculus repens L.
Ranunculus bulbosus L.
Viola palustris L.
Potentilla Anserina L.
Potentilla Tormentilla Neck.
Myriophyllum spicatum L.
Hippuris vulgaris L.
Gentiana cruciata L.
Menyanthes trifoliata L.
Salix repens L.
Sparganium simplex Hudson.
Sparganium minimum Fries.
Potamogeton heterophyllus Schreber.
Potamogeton Zizii Roth.
Eleocharis palustris R. & S.
Eleocharis uniglumis Link.
Scirpus lacustris L. (?).
Carex arenaria L. (?).
Carex Goodenovii Gay.
Carex flava L.
Carex rostrata Stokes.

(*c*) The Southern Element.

A small number of the Barnwell plants were forms which have an even more restricted northern range at the present time, and these were designated the 'southern element' in the flora. The majority of them are now found as far north as about 63° lat. N., but in one or two cases they extend only to Denmark or to the extreme south of Scandinavia. This southern element is as follows:—

Ranunculus Lingua L.
Ajuga reptans L.
Carpinus Betulus L.
Potamogeton obtusifolius M. & K.
Potamogeton densus L.
Zannichellia pedunculata Reichberg.
Naias marina, var. *intermedia* A. Braun.
Carex vulpina L. (?).
Carex divisa Hudson.

It is difficult to account for the presence of such plants as *Carpinus Betulus* and *Potamogeton densus* in association with the Arctic species previously enumerated. But the majority of the plants forming this southern element had seeds too delicate in character to have survived from an earlier deposit; and, since their preservation was of exactly the same type as that of the Arctic plants from Barnwell, they were probably contemporary with the Arctic species. Perhaps the difference in altitude between the low-lying tract of the plain around Barnwell, and the more elevated ground in the higher reaches of the river, was sufficient to differentiate between the conditions in the two areas to such an extent that, while on the Chalk hills the most Arctic species could grow, in the lowlands the southern element could find an habitation.

(*d*) The Calcareous-Soil Group.

Considering that there was a Chalk outcrop in the upper reaches of the Cam, comparatively close to Barnwell, it is not surprising to find that the flora included plants of a definitely calcicole type. These were :—

Thalictrum minus L.	(?) *Linum Præcursor* Reid.
Papaver alpinum L.	*Dryas octopetala* L.
Arenaria gothica Fries.	*Gentiana cruciata* L.
(?) *Helianthemum* sp.	

The plants *Helianthemum* and *Linum Præcursor* are placed here tentatively, for the recent species of *Linum* and *Helianthemum* thrive best on a calcareous soil, and the unidentified rock-rose and the extinct linseed may perhaps have shared this character.

(*e*) The Estuarine Group.

The presence of the following plants at Barnwell suggests tidal influence :—

Rumex maritimus L.	*Eleocharis uniglumis* Link.
Zannichellia pedunculata Reichberg.	*Carex arenaria* L. (?).
Naias marina, var. *intermedia* A. Br.	*Carex divisa* Hudson.

With the possible exception of *Zannichellia pedunculata*, no single plant in this list can be regarded as affording incontrovertible evidence of tidal influence; but, when we consider the group as a whole, the marine tendency of all these plants does seem to afford cumulative evidence of such a factor. The suggestion of marine influence is not unreasonable, in view of the previous history of the Fenland: for, even at the present time, a very small estuarine flora still survives far inland in the county of Cambridge, and this element must have been larger before the comparatively modern system of drains and sluices controlled the inflow of tidal waters.

It would appear, therefore, that the Barnwell Flora owed its complexity to the admixture, in a single deposit, of leaves and seeds from various parts of the river-basin. It included remains of Arctic and Chalk plants which were transported some little distance before they were incorporated in the peat-seams, and were therefore usually represented by but few specimens except in the case of the larger and tougher seeds. There were also plants from the low-lying tract bordering the Fenland, where tidal influence was probably felt.

The facts here stated, which were made apparent by the study of a particular flora, have a bearing on the whole question of peats in river-gravels. Considering that plants from several ecological units must necessarily have been mixed together in any river-gravel in which a flora is preserved, considerable variation between

any two such fossil floras is to be expected, even if they were actually contemporary; for it could rarely happen, in the case of two rivers, that the areas drained supported exactly the same plant-formations in precisely the same proportions.

Difference, then, in detail, must almost always be expected, though, naturally, two contemporary floras so differing may still bear the stamp of the more general conditions under which they flourished—such, for instance, as the climatic conditions. Comparison, with the view of establishing the relative age of two floras, seen in such close perspective as in the case of those from the Pleistocene, is therefore difficult; and the difficulty is increased by the fact that in any two cases conditions of preservation may have varied, so that whereas, in the one instance, certain delicate forms were preserved, in the other, on the contrary, they were destroyed before fossilization could take place. Further, an inadequate study of one or of both of two deposits may mean that characteristic forms escaped notice, and this risk should always be borne in mind in any attempted comparison, however much material was examined; for the fossil content frequently differs in richness from seam to seam, and it must sometimes happen that the investigation of one more sample of peat would reveal the presence in a flora of plants previously unrecorded.

All that can be said safely, therefore, in comparing two Pleistocene floras is that both, say, are Temperate, or both Arctic, so that they may have been contemporary. This is essentially true of the Lea and Cam-Valley Floras, both of which yielded Arctic plants, and both of which, judging by stratigraphical evidence, appear to have been of Upper Palæolithic date.

The late Clement Reid, in a note mentioned previously,[1] suggested the contemporaneity of these two floras on the grounds that:

(*a*) there was a correspondence in the plant-assemblages, and that

(*b*) not only did the same species occur, but the same Arctic species were missing.

Recent evidence does not accord with these statements, for, beyond the fact that both floras were Arctic, yielding certain of the same widely-distributed Arctic and Temperate forms, there appears to be no close correspondence between the two plant-assemblages, as will be shown subsequently. Moreover, some of the Arctic species which were supposed to be absent from the two areas were found lately at Barnwell, illustrating once more the fact that inferences based on negative evidence are always liable to modification as the result of subsequent discovery.

This being borne in mind, some conclusions in regard to the differences between the floras have been deduced from the available evidence. But the fact that these conclusions are purely tentative cannot be too strongly emphasized, for at any moment further research may render them untenable. First, then, while the flora

[1] See J. E. Marr, Q. J. G. S. vol. lxxv (1919–20) p. 227.

in both cases was almost equally large, there was an amazing number of plants represented in either list that were not recorded in the other one—in fact, only about thirty species, or roughly a third of the plants known to occur at Barnwell, were common to the two deposits (see the floral list). Further, different families were represented in the two cases: thus, out of a total of twenty-seven families in each locality, the following from Barnwell were not found in the Lea Valley: Papaveraceæ, Fumariaceæ (?), Cistaceæ, Geraniaceæ, Saxifragaceæ, Dipsaceæ, Campanulaceæ, Ericaceæ, Scrophulariaceæ, and Primulaceæ; while these from the Lea Valley were unrecorded at Barnwell: Portulaceæ, Leguminosæ, Umbelliferæ, Caprifoliaceæ, Valerianaceæ, Compositæ, Solanaceæ, Chenopodiaceæ, Urticaceæ, and Alismaceæ. The apparent absence in the Barnwell peat of Composites which were represented in the Lea Valley by several different species is rather curious, in view of the present abundance and wide distribution of the members of that family, and in view also of the preservation at Barnwell of numerous delicate seeds.

Another difference brought out by a study of the floral lists is that the Arctic character of the flora was far more pronounced at Barnwell than in the Lea Valley, for in the former locality 42 per cent. of the plants were Arctic and Alpine species, as against 22 per cent. in the latter area. Similarly, the number of plants not now indigenous in Britain (chiefly Arctic and Alpine species) was greater at Barnwell, and included the following:—

Ranunculus aconitifolius L.
Papaver alpinum L.
Silene cælata Reid. (Extinct.)
Lychnis sp.
Arenaria biflora L.
Geranium sp. y.
Linum Præcursor Reid. (Extinct.)
Scabiosa sp.
Campanula sp.
Gentiana cruciata L.
Primula sp.
Armeria arctica Wallr.
Salix Polaris Wahl.
Carex capitata L.
Carex ustulata Wahl.

In the Lea Valley this class of plants was considerably smaller, consisting of

Silene cælata Reid. (Extinct.)
Lychnis sp.
Linum Præcursor Reid. (Extinct.)
Potentilla cf. *nivalis*.
Armeria arctica Wallr.

The occurrence of the extinct plants *Silene cælata* and *Linum Præcursor* in both localities is not necessarily a proof that the peat-beds were contemporary; for, given suitable conditions, these species would have been preserved in deposits formed at any point along their time-range.[1]

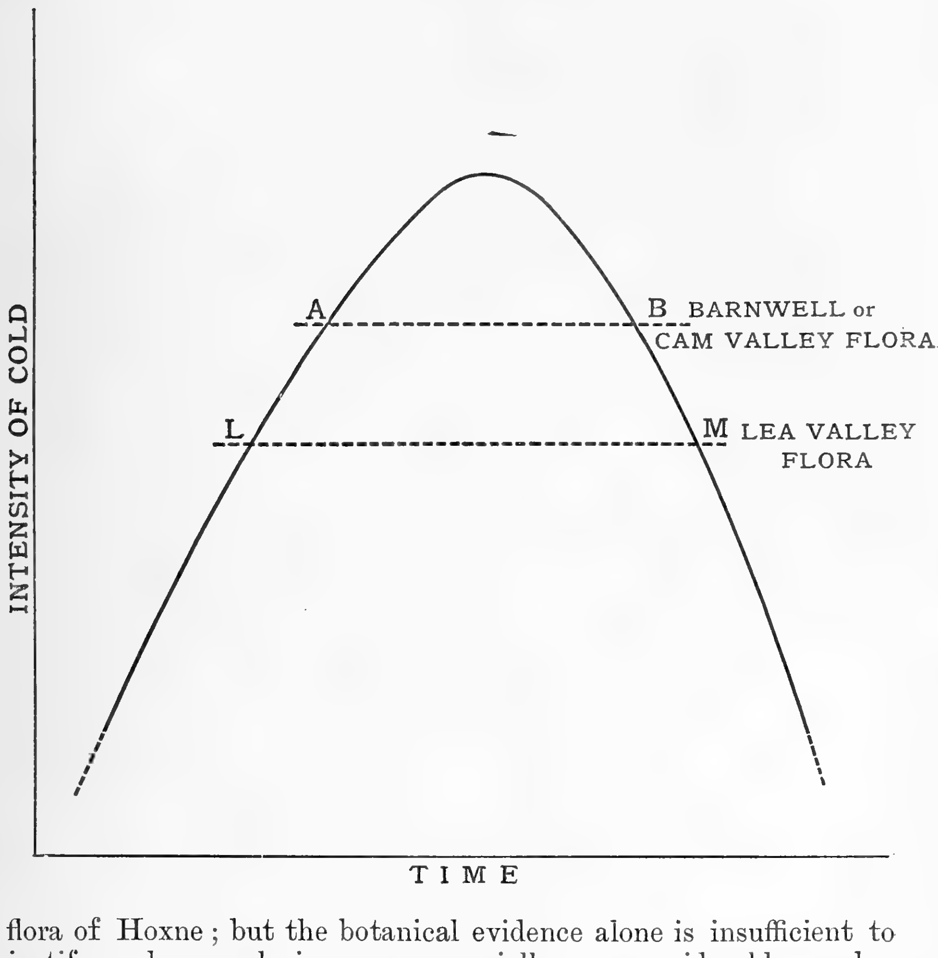
Again, the calcareous-soil element was more clearly defined in the Barnwell Flora than in that of the Lea Valley, and this constitutes another difference between them.

[1] That is, during the existence of the genera, from their evolution to their extinction.

A definite cause must have underlain such differences, and therefore the question arises: 'To what can they be attributed?'

Supposing that the two floras were separated by a considerable interval of time, that alone would probably have accounted for their dissimilarity, and this would have been the case had they lived during different cold periods. On this hypothesis, the Barnwell plants might have co-existed approximately with the Arctic

Fig. 2.—*Curve representing the relative positions of the Cam and Lea-Valley Floras, based on the theory that the former lived nearer the climax of a cold period than the latter.*



flora of Hoxne; but the botanical evidence alone is insufficient to justify such a conclusion, more especially as a considerable number of years have elapsed since the Hoxne Flora was investigated, while the stratigraphical evidence which places the Barnwell gravels fairly late in the Pleistocene renders this interpretation improbable.

If, on the other hand, the two Arctic floras lived within the same cold period, their differences might be partly explained by supposing that the Cam-Valley Flora existed whan the cold was near its climax, while the Lea-Valley Flora lived when it was less

marked: wherefore, of the two floras, that from the Cam Valley would naturally show the more pronounced Arctic features. Hence, if the two were supposed to lie on a curve, so drawn that ordinates represent intensity of cold and abscissæ represent time, the Cam-Valley Flora would lie at a higher point on the curve than the Lea-Valley Flora.

Thus A or B (fig. 2, p. 15) would represent diagrammatically the relative position of the Cam-Valley Flora if the Lea-Valley Flora were supposed to lie at L or M on the curve. If L were its position, the Cam-Valley Flora would be the younger of the two, whether it were represented by A or B, and similarly if M were its position, then the Cam-Valley Flora would be the older.

Another possible explanation of the more striking character of the Arctic element at Barnwell is based on the theory, previously suggested, that the most Arctic plants grew on the high ground upstream. But the high ground, which both in the Lea and in the Cam Valleys was formed by Chalk, was near to Barnwell, in the Cam Valley, while it lay much farther away from Ponders End in the Lea Valley; thus seeds from the upland tract had a good chance of incorporation in the peat-seams at Barnwell, whereas in the Lea Valley they were more liable to be destroyed during transport.

The relative distance between the peat-beds and the Chalk uplands in the two localities would also explain why the calcareous element as well was better represented at Barnwell than at Ponders End.

Perhaps, if the suggestion that the floras lived during the same cold period be correct, both the causes indicated here may have helped to produce a certain individuality in the plant-beds of the two areas.

Though it is possible, then, to regard the floras as contemporary, the evidence yielded hitherto by the plants is insufficient to justify any definite conclusion, and, at present, it looks as if the testimony afforded by other lines of research must be awaited for the final solution of the problem.

I desire to take this opportunity of thanking Mrs. Reid for generously allowing me to use the magnificent Reid Collection, and for the assistance which she willingly gave me while I was at work on these beds. My thanks are also due to Prof. J. E. Marr, F.R.S., who kindly gave me every facility for working in the Sedgwick Museum. I am further deeply grateful to Miss G. L. Elles, D.Sc., for reading and criticizing this paper in manuscript, and for all the ungrudging help and encouragement which she has always afforded me.

Appendix I.

Notes on Certain Species recorded at Barnwell.

Salix repens.

This plant was represented at Barnwell by its leaves, and, if we judge by their abundance, it must have occupied considerable areas. As it is a chalk-hating (calcifuge) plant, it may either have lived in the lowland tract where the beds below the Chalk were exposed, or it may have occupied areas covered by gravels of some thickness, higher up-stream, on the Chalk outcrop.

Draba incana and Cochlearia officinalis.

These two Crucifers are well-known instances of plants which flourish in Arctic-Alpine situations, but also along sea-coasts. Since however, they are very common and widely-distributed Arctic plants, it seems probable that their presence in the Barnwell Flora was due to climatic conditions rather than to tidal influence, wherefore they are classed with the Arctic, and not with the estuarine plants in this paper.

Appendix II.

The Barnwell Flora, showing the Distribution of the Fossil Plants through the Different Seams.

The following abbreviations are used for the seams examined :—

Lowest	= The lowest seam in the section.	In the section below the tramway.
x	= The lowest seam but one in the section. This was the seam examined by Mr. Clement Reid, several additions to his list have since been made.	
X	= A seam above the gravel-wedge.	
4 Parl.	= Four thin, closely-associated, parallel seams above the gravel-wedge.	
M.A.T.	= The middle one of three seams at the point indicated in fig. 1, pp. 6–7.	In the section above the tramway.
T.A.T.	= The highest of three seams at the same point.	

This terminology was employed in labelling the actual specimens, which have been deposited in the Sedgwick Museum.

Species recorded.	Seams. Lowest.	x.	X.	4 Parl.	M.A.T.	T.A.T.	Comment on Specimens.
Thalictrum alpinum L.	×	×	×	×	×	×	
Thalictrum minus L.	...	...	...	×			
Batrachium hederaceus L.	...	×	×	×	×		
Batrachium spp.	...	...	...	×	×	...	Several species. Not in the Reid Collection.
Ranunculus aconitifolius L.	...	×	×	×	×	×	In various stages of preservation, seen in the recent specimens after treatment by boiling and then rubbing to a varying extent, in order to simulate the conditions of fossilization.
Ranunculus Flammula L.	...	...	...	...	×		
Ranunculus Lingua L.	...	?	...	...	×		
Ranunculus repens L.	...	?	×				
Ranunculus bulbosus L.	...	×					
Papaver alpinum L.	...	...	...	...	×	...	The fossil had all the characters of *Papaver alpinum*, but was slightly larger than seeds of that species from the only gathering in the Reid Collection.
Fumaria sp. ?	...	...	...	...	×	...	Not in the Reid Collection.
Draba incana L.	×	×	×	×			
Cochlearia officinalis L.	...	...	...	...	×		
Helianthemum sp.	...	...	×	...	...	...	The outer skin of the seed had perished during fossilization.
Viola palustris L.	...	×					
Silene cælata Reid	×	×	×	×			
Lychnis sp.	...	×	...	...	...	...	Not in the Reid Collection.
Arenaria sedoides L.	...	...	×	×	...	×	
Arenaria biflora L.	...	...	×				
Arenaria gothica Fries	...	...	...	...	×	...	The seed broke after identification, the remains were mounted and deposited with the other specimens in the Sedgwick Museum.
Arenaria sp.	...	...	...	×	...	...	Preservation good, but the species was not represented in the Reid Collection.
Stellaria sp. ?	...	...	...	...	×	...	Not in the Reid Collection.
Caryophyll seed	...	×					
Geranium sp. x	×	×	×	×	×	×	The characters of this species were found scattered throughout the genus *Geranium*. Species not in the Reid Collection.
Geranium sp. y	...	...	×	...	...	...	Carpel. Nearest to *G. sanguineum*, but smaller than that species. Not in the Reid Collection.
Linum Præcursor Reid	×	×	×	×			
Potentilla Anserina L.	...	×	×	×	×		
Potentilla argentea L.	...	...	×				
Potentilla alpestris Hall	...	...	...	×	...	...	The thin prolongation seen on one side in the recent seed is broken in the fossil, probably a natural result of fossilization.
Potentilla fruticosa L.	...	...	×	...	...	...	Hairs (or their bases) preserved at the broad end of the seed.

Species recorded.	Seams. Lowest.	x.	X.	4 Parl.	M.A.T.	T.A.T.	Comment on Specimens.
Potentilla Tormentilla Neck.	×	×	×	×	×		
Rubus sp.	...	×	...	...	...	...	Badly preserved.
Dryas octopetala L.	...	...	×	...	×		
Myriophyllum spicatum L.	...	×	...	×	×		
Hippuris vulgaris L.	...	×	×	×	×	×	
Saxifraga oppositifolia L.	...	...	...	...	×	×	
Scabiosa sp.	...	...	...	×	...	...	Not in the Reid Collection.
Campanula sp.	...	...	...	×	...	...	Not in the Reid Collection.
Vaccinium uliginosum L.	×	..	...	...	×	×	Leaves. The lower epidermis was destroyed, showing the spongy tissue and often the upper epidermis also. Leaves of the recent plant were prepared for comparison by soaking and rubbing.
Gentiana cruciata L.	...	...	...	×	...	...	Surface-striations were closer than those in the majority of recent seeds examined, but fell within the range of variation of the species. In allied species also a similar range of variation was observed.
Menyanthes trifoliata L.	×	×	×	×	×	×	The outer surface of the seeds was often partly destroyed.
Bartsia sp.	...	...	×				
Ajuga reptans L.	×						
Primula scotica Hook.	...	...	...	...	×		
Primula sp.	...	...	...	...	×	...	Not in the Reid Collection.
Armeria arctica Wallr.	×	×	×	×	×	×	A few undeveloped specimens showed crowded pollen-grains in the calyx.
Rumex maritimus L.	...	...	×				
Polygonum viviparum L.	...	×	×	...	...	×	The specimens were usually broken, though all showed the distinctive ornamentation. The original determination was based on a good and complete specimen.
Salix cinerea L.	...	×					
Salix repens L.	×	×	×	×	×	×	
Salix Arbuscula Fries	×	×	...	×	×	...	In many cases the hairs on the leaves were well preserved.
Salix Lapponum L.	×	×	×	...	×		
Salix herbacea L.	...	×	...	...	×		
Salix Polaris Wahl. (?)	...	...	...	...	×	×	
Salix reticulata L.	...	×	...	×			
Betula nana L.	×	×	×	×	×	×	
Carpinus Betulus L.	...	×					
Sparganium simplex Hudson	...	...	...	×			
Sparganium minimum Fries	...	×					
Potamogeton heterophyllus Schreb.	×	×	×	×			
Potamogeton Zizii Roth	...	...	×	×	×		
Potamogeton obtusifolius M. & K.	...	×	...	×	×		
Potamogeton filiformis Nolte	×	×	×	×	×		
Potamogeton densus L.	×	×	×	×			
Potamogeton spp.	×	...	×	...	×	...	Several species. • Not represented in the Reid Collection.
Zannichellia pedunculata Reichb.	×	...	×	×			

Species recorded.	Seams. Lowest.	x.	X.	4 Parl.	M.A.T.	T.A.T.	Comment on Specimens.
Naias marina, var. *intermedia* A.Br.	...	...	...	×			
Eleocharis palustris R. & S.	...	×	×	×	×	×	
Eleocharis uniglumis Link	...	...	×	×	×		
Rhynchospora sp.?	×	...	...	...	...	...	Not in the Reid Collection. Badly preserved.
Scirpus lacustris L. (?)	...	...	...	...	×	...	Badly preserved.
Eriophorum polystachion L.	...	...	...	×			
Eriophorum latifolium Hoppe	...	...	...	×			
Carex capitata L.	×	×	×	×	×	×	
Carex arenaria L. (?)	×	...	×		...	...	Badly preserved.
Carex divisa Hudson	...	...	...	×			
Carex vulpina L. (?)	...	×					
Carex lagopina Wahl.	...	...	?	×	×	...	The fossils were very slightly larger than the recent specimens, which were not fully developed, also their surface-sculpture was a trifle coarser than that of the recent seeds. In other respects, however, including the character of the utricle, the fossils and recent specimens agreed exactly.
Carex Goodenovii Gay	×	×	×	×	×	×	One specimen had a complete utricle, and many had part of the utricle preserved.
Carex atrata L. (?)	×	...	...	×	×	...	Badly preserved.
Carex ustulata Wahl.	?	...	×	×	×	×	
Carex capillaris L.	?	...	×	×	×		
Carex glauca Scop. (?)	...	...	...	×	×	...	Badly preserved.
Carex flava L.	...	...	...	...	×	...	Slightly less cuneate than specimens in the Reid Collection, but agreeing with the recent seeds in every other respect.
Carex rostrata Stokes	...	...	...	×			
Carex spp.	×	×	×	×	×	×	Numerous, but as a rule badly preserved. Many species not represented in the Reid Collection.
Isoëtes lacustris L.	...	×					
Selaginella spinulosa A. Braun	×	×	×	×	×	×	
Chara sp.	×	×	×	×	×	×	
89 species, representing 27 families.	29 species.	42 species.	43 species.	49 species.	47 species.	20 species.	

Discussion.

Prof. J. E. Marr congratulated the Author upon the valuable addition which she had made to our knowledge of the Pleistocene geology of Cambridge. He called attention to the occurrence of unworn implements of Upper Palæolithic age on a terrace somewhat north of Barnwell, and at a height less than that of the plant-bearing deposits. This proved that the plant-deposits were formed prior to the end of Upper Palæolithic times. The occurrence of *Zannichellia* in these beds was by him unexpected, and probably complicated the question as to various earth-movements in later Pleistocene times.

Mrs. E. M. Reid said that the Author's work was most valuable. She agreed with the Author that the botanical evidence threw no light on the absolute age of the Arctic floras of the Cam and Lea Valleys, but that it did throw light on their relative ages, and showed that these were not identical. She had been led to this view by comparing the two Arctic floras with the Temperate floras which preceded (Cromerian) and succeeded (present day) the Glacial Period. The two Arctic floras, as known, contain almost the same number of species; but, whichever comparison is made, the Lea-Valley flora is seen to contain about half as many again of Temperate forms as the Cam-Valley flora. This shows that the Cam-Valley flora lived nearer to the maximum of cold than the Lea-Valley flora, but does not show whether the Lea-Valley flora was earlier or later. Of the 145 known Cromerian species, only 16 are found in the Cam-Valley flora, a definite indication that the Cromerian flora was mostly exterminated in Southern Britain, and must have survived outside our islands. A great deal is now known of these Arctic floras. With the return of warmth they were driven to higher latitudes and higher altitudes; some species reached both, some only one or the other, and some neither: the latter were exterminated. In the speaker's view, plant life has been driven to and fro, and up and down the mountains, by stress of climate. If we can but follow its migrations, we shall have a most valuable botanical time-record, by which to trace changes of climate. If such a record is ever made (and the speaker saw no reason why in the future it should not be made), it would be by the aid of such reliable and valuable work as that done by the Author.

Prof. W. J. Sollas expressed his satisfaction in learning that Prof. Marr's discovery of the *Dryas* Bed at Cambridge had led to such valuable results, and congratulated the Author on a remarkable contribution to our knowledge of the Pleistocene flora. We owe to Dr. and Mrs. Clement Reid an ancillary branch of investigation which is bearing excellent fruit, and it is most fortunate that a Cambridge botanist has appeared to continue its cultivation.

It was to be hoped that the *Dryas* flora is confined to a single horizon. Whether it really was so or not might be still an open

question. In Scandinavia it seemed to be constant in its appearance at the close of the last Glacial episode, during the later stages of the emergence which followed upon the *Yoldia* depression, and in Gotland it occurs along with *Zannichellia polycarpa* below the deposits of the *Ancylus* lake. Prof. Marr's discovery of Palæolithic implements at a higher level than the plant-bed provided a new problem, and showed the necessity for further investigation. The Author had furnished a firm basis of fact; subsequent enquiry might increase, but could not diminish its value.

The AUTHOR thanked those present for the kind reception given to her paper. In reply to Prof. Sollas, she regretted that, up to the present, no comparison with the Pleistocene floras of the Continent had been made. She ventured to differ from Mrs. Reid as to the extermination of the Temperate flora by the cold; for, although the Cromerian species found in the Lea and Cam floras were few, the species recorded from the Cromerian would constitute but a small proportion of the Temperate flora then living, and there was no dearth of Temperate species in these two Arctic beds, for such constituted 78 and 58 per cent. of these floras respectively. A certain element comprising the more southern forms was doubtless exterminated; but, pending further discoveries, she felt that the presence of so large a proportion of Temperate species associated with the Arctic species pointed to the fact that, far from being exterminated, much of the flora was able to endure the changed conditions, and to live on side by side with the Northern invaders.

3. A New Species *of* Blattoid (Archimylacris) *from the* Keele Group (Radstockian) *of* Shropshire. By Herbert Bolton, M.Sc., F.R.S.E., F.G.S. (Read February 2nd, 1921.)

[Plate I.]

I am indebted to the Geological Survey for the opportunity of examining a fragment of an insect-wing discovered by Mr. J. Pringle, F.G.S., while engaged in the examination of core-material collected in 1919 by Mr. T. C. Cantrill, B.Sc., F.G.S., from a new borehole for water at Slang Lane, Wellington (Shropshire).[1]

The core-material came from some level between the surface and 97 feet, the actual depth being undeterminable because the chisel was used in boring. From an examination of the plant-remains, Mr. Pringle is of opinion, and Mr. Cantrill's field-observations bear him out, that the beds belong to the Keele Group.

The wing-fragment and its impression lie upon the surfaces of two pieces of red marl, and are not easily recognizable. Its discovery by Mr. Pringle is testimony to the thoroughness of his search of the material.

Enough of the wing is present to enable us to determine the genus, and to show that the form is new to British Coal Measures, and sufficiently distinct from Continental species to merit specific distinction. The characters of the subcosta and the interstitial neuration clearly indicate that the wing belongs to the genus *Archimylacris*, and as such I describe it.

Archimylacris pringlei, sp. nov.

Holotype.—The basal two-thirds, and impression of a tegmen or forewing, lying upon the irregular surface of two small pieces of red marl, and partly obscured by plant-remains. Length = 18 mm. Collection of the Geological Survey, Jermyn Street, Reg. Nos. 30725–726.

Horizon and locality.—Keele Group, Upper Division of the Coal Measures; from rocks between the surface-level and 97 feet in the borehole at Slang Lane, Wellington (Shropshire).

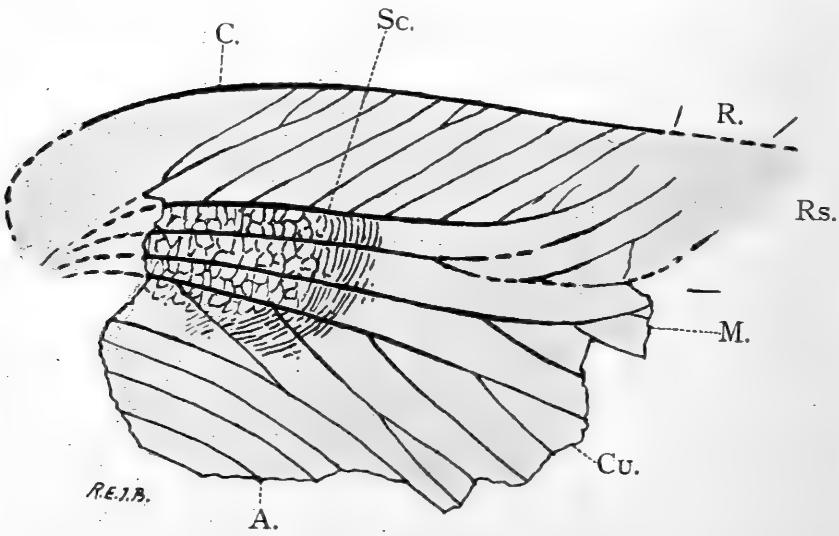
Specific description.—Wing twice, or two and a half times, as long as wide. Outer margin flatly curved; subcosta strap-shaped, and giving off numerous parallel branches to the outer margin. Radius dividing just beyond the middle of the wing, and giving off a radial sector. Median parallel to the radius, and

[1] 'Summary of Progress for 1919' Mem. Geol. Surv. 1920, p. 8.

dividing a little farther out than the radius; evidently reaching the inner half of the wing-margin. Cubitus curving gently inwards, and giving off inward branches, only four of which are shown. Anal area long, and reaching to the end of the basal third of the inner margin. Integument thin, interstitial neuration of close parallel cross-nervures, except in the basal area, where the neuration becomes reticulate.

Description.—The costal margin is well defined, flatly convex over the greater part of its length, and well rounded into the point of attachment. The subcosta is parallel to, and widely spaced from, the costal margin, and extends over two-thirds of the length of the wing. It gives off eight or nine oblique and parallel

Fig. 1.—Archimylacris pringlei, *sp. nov.* × 3.



A. = Anal. Sc. = Subcosta. R. = Radius. M. = Median.
C. = Costa. Cu. = Cubitus. Rs. = Radial sector.

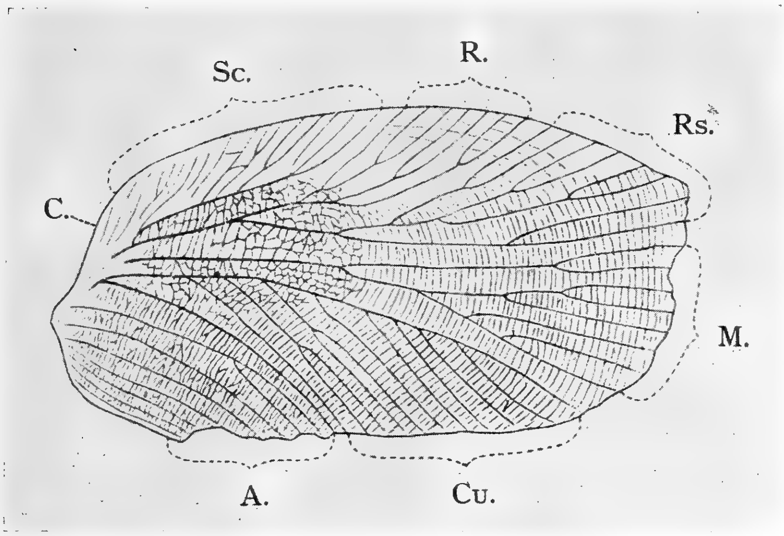
branches, all reaching the margin. The first branch is represented only by a small fragment of the middle of its length; the second forks twice into three twigs, while the third, fourth, and fifth fork near the margin. There is also a small undeveloped ramus, branching off from the subcosta at the point where the latter bends forwards towards the margin.

The radius is incomplete, the main stem diverging slightly from the subcosta, and dividing by a wide fork at a point between the seventh and eighth branches of the subcosta. The first of the radial divisions is the true radius, and the inner branch is the radial sector. The radius can be traced almost up to the margin, and shows a single forking. The radial sector goes out in a straight line to the wing-apex. The median has a slight divergence from

the radius, and is closer to it than is the latter to the subcosta. It gives off the first inward branch a little distance from the point of origin of the radial sector, and feeble traces of a second branch can be discerned farther out. It must have possessed from four to six branches, adequately to support the area of the wing to which it is directed.

The cubitus starts out from the middle of the base of the wing, gradually bending inwards in its course to the most distal part of the inner margin. Four inwardly directed branches are given off, the first passing under the first anal, owing to the fracture of the wing. The second divides by a simple fork in the middle of its length, while the third and fourth are undivided. All the branches of the cubitus come off at wide angles, and so the area enclosed by this vein is large.

Fig. 2.—Archimylacris desaillyi *Leriche.* × 3.



A. = Anal. Sc. = Subcosta. R. = Radius. M. = Median.
C. = Costa. Cu. = Cubitus. Rs. = Radial sector.

The anal area has broken away from the rest of the wing, and moved a little forwards, overlapping the first branch of the cubitus. The anal furrow is no longer distinguishable, having lain along the line of fracture. Six anal veins are present, the first somewhat obscure, and the second and third possibly united at their base.

The interstitial neuration consists of a compact series of close-set transverse nervures, which, in the basal areas between the radius, median, and cubitus, anastomose laterally, forming a fine network.

Affinities.—I was at once struck with the likeness of this specimen to the form described by Leriche,[1] as *Archimylacris*

[1] Ann. Soc. Géol. Nord, vol. xxxvi (1907) p. 164 & pl. ii.

desaillyi, and therefore sent an enlarged photograph of the specimen to Dr. P. Pruvost, Lille University, in whose custody Leriche's type now is. Dr. Pruvost recognized the likeness, but thought that it was more closely allied to a form referred by himself first to *A. belgica* Handlirsch, and later described by him as a new species, *A. lerichei*.[1]

Dr. Pruvost takes note of one feature which has caused me to regard the specimen as nearer to *A. desaillyi* than to *A. lerichei*, namely, the great differences in the form of the distal end of the costal vein. In *A. lerichei*, the subcostal is not sharply bent outwards as in this specimen and in *A. desaillyi*, but is decidedly oblique, so that the costal area is much less strap-shaped than in either. Nor is the general course of the subcosta so truly parallel to the margin.

TABULATED COMPARISON.

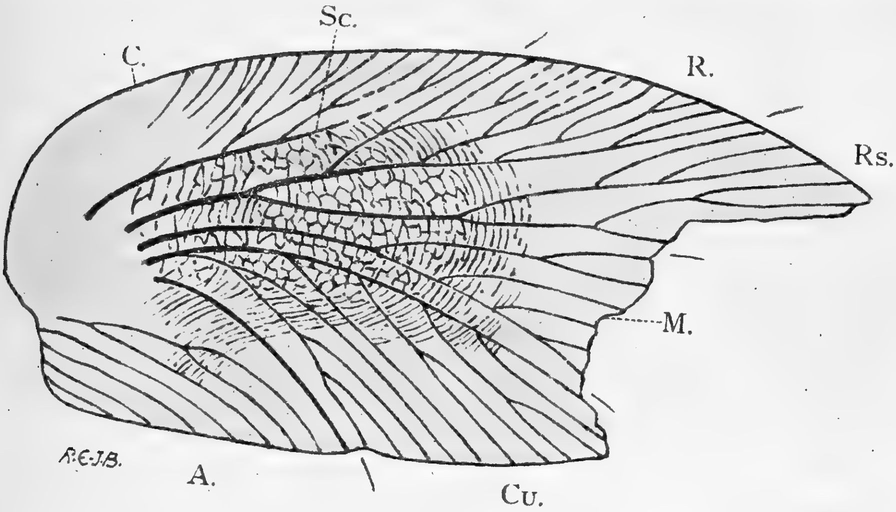
A. pringlei, sp. nov.	*A. desaillyi* Leriche.	*A. lerichei* Pruvost.
Costal Area.		
Strap-shaped, widely spaced from wing-margin.	Strap-shaped, widely spaced from wing-margin.	Outer third oblique to wing-margin.
Subcostal Vein.		
Numerous divisions, mostly forking.	Numerous divisions, mostly forking.	Few divisions, much branched.
Radius Vein.		
Few branches. Radial sector arising opposite outer fourth of subcosta.	Seven branches. Radial sector arising opposite outer third of subcosta.	Twelve branches. Radial sector arising opposite middle of subcosta.
Radial Sector.		
Branching not known.	Eight branches.	Seven to eight branches.
Median Vein.		
Branches beyond origin of radial sector.	Branches opposite first fork of radial sector.	Branches much beyond origin of radial sector.
Cubitus Vein.		
First branch simple, second forked.	First branch simple, second and third forked.	First branch dividing into four, second simple, third and fourth branched.
Anal Veins.		
Undivided.	First vein only forked.	First anal forking twice.
Interstitial neuration.		
Transverse nervures, except in the median basal part of the wing, where it is reticulate.	Transverse nervures, except in the median basal part of the wing, where it is reticulate.	Transverse nervures, except in the median basal part of the wing, where it is reticulate.

[1] 'Les Insectes Houillers du Nord de la France' Ann. Soc. Géol. Nord, vol. xli (1912) p. 335 & pl. ix, figs. 4–4*a*; see also 'Introduction à l'Étude du Terrain Houiller du Nord du Pas-de-Calais: La Faune Continentale du Terrain Houiller du Nord de la France' Paris, 1919 [1920], p. 154 & pl. viii, figs. 5–6.

It is evident that the relationship between these three species is very close, yet the British specimen is clearly distinct. I have much pleasure in giving Mr. Pringle's name to the species discovered by him.

Observations.—The occurrence of a fossil Blattoid in Measures formerly regarded as Permian, and now classed as Upper Coal Measures, is worthy of comment, especially as the fossil is more closely related to Blattoids found in the Coal Measures of Liévin, Northern France, than to any British species. The Coal Measures of Liévin are generally accepted as being at the summit of the Westphalian Series. Dr. Pruvost writes that he has previously

Fig. 3.—Archimylacris lerichei *Pruvost.* × *3.*



[For explanation of lettering, see fig. 2, p. 25.]

drawn attention to the fact that the fauna at the top of the Coal Measures in Great Britain (Keele Group, Newcastle-under-Lyme Group, Etruria Group) does not differ (except in the presence of *Anthracomya calcifera*, peculiar to England) from the fauna at the top of the Westphalian in Northern France. The occurrence of an *Archimylacris* in the Keele Group confirms him in this opinion.

The Keele Group in which the insect-wing was found was formerly regarded as Permian, and is so marked upon the older geological maps; but the researches of the Survey Officers, as also the palæobotanical work of the late Dr. Newell Arber, and more especially that of Dr. Kidston, have conclusively proved their Coal-Measure character. These workers regard the Keele Group as part of a true Upper Coal-Measure Series, widely spread over

Shropshire and adjacent counties. Dr. Kidston[1] has given the name 'Radstockian' to the Series which includes the Keele Group.

I desire to express my indebtedness to Mr. T. C. Cantrill, who collected the core-material, afterwards supplied me with information concerning the Keele Group, and checked my statements as to the stratigraphy.

EXPLANATION OF PLATE I.

Archimylacris pringlei, sp. nov. Wing-fragment and impression magnified 4·8 diameters.

Discussion.

Dr. J. W. Evans asked what was the earliest horizon at which insect-remains were found, and whether they showed from the first a variety of different types.

Mr. E. E. L. Dixon congratulated the Author on his successful determination of the affinities of the Blattoid, and Mr. Pringle on having added another to his long list of 'captures' of Coal-Measure arthropods. He contrasted the conformity that existed between the Keele Group and the underlying part of the Coal Measures with the unconformable relations of the Continental Stephanian, and mentioned the difference between the correlation of Dr. R. Kidston, who referred the Keele Group to the Stephanian, and that of the late Dr. E. A. Newell Arber, who regarded the group as the top of the Westphalian. Every piece of zonal evidence was, therefore, important, and he enquired whether the degree of specialization of the Wellington Blattoid had enabled the Author to compare its age with those of Liévin, the age of which was known.

The Author thanked the Fellows for their kind reception of his paper, and, in answer to Dr. J. W. Evans, replied that some doubt existed as to the earliest possible occurrence of fossil insects. Brongniart had recorded the wing of a supposed Blattoid from the Silurian, under the name of *Palæoblattina douvillei*, though the general opinion was that the structure was not of insect origin, but in all probability a portion of a cephalic spine of a trilobite. Sir J. W. Dawson recorded the existence of undoubted insect-remains in the Fern Ledges of New Brunswick, and classed the deposits as Devonian. The recent researches of Dr. Marie Stopes had, however, shown that they were of Carboniferous age.

Undoubted insect-remains have not as yet been recorded from any rocks older than the Upper Carboniferous, where they appear in considerable numbers. They show a degree of specialization such as could hardly have been reached without a long ancestry. This was especially true of the Blattoids, and for this reason the Author believed that insect life must have first appeared at a much

[1] Q. J. G. S. vol. lxi (1905) p. 319.

Fig. 1. × 4·8.

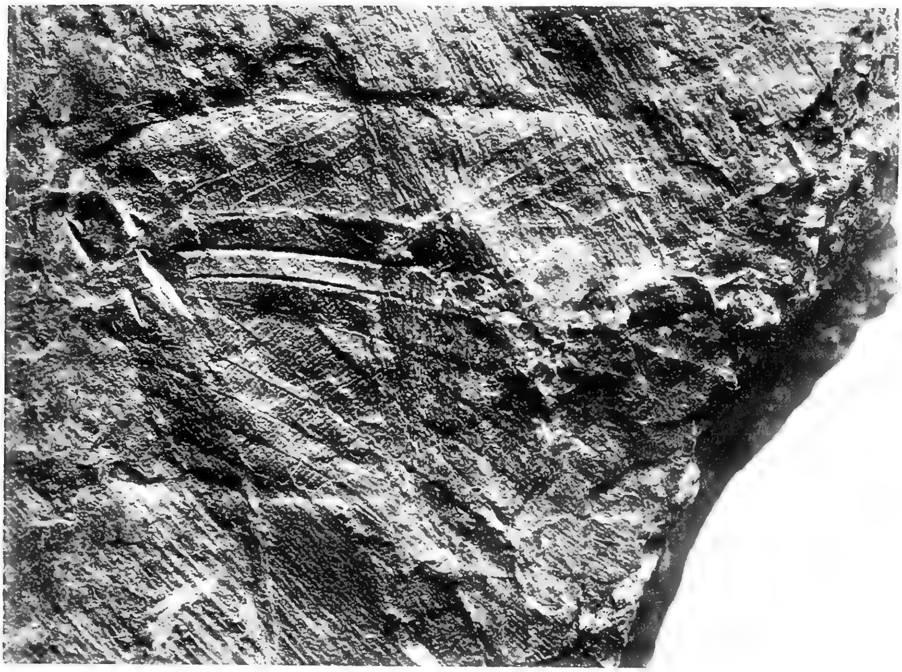
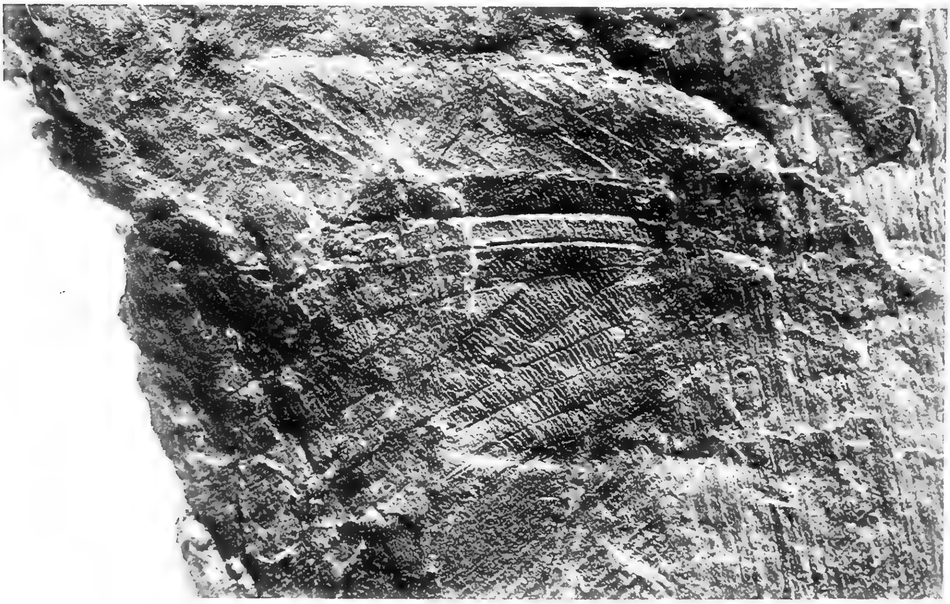


Fig. 2. × 4·8.



J. W. Tutcher, Photo.

Bemrose, Collo., Derby.

ARCHIMYLACRIS PRINGLEI, sp. nov.

earlier period. He was firmly convinced that the most primitive insects would yet be found in Devonian rocks, or in the Upper Silurian. The oldest insect forms known are generalized types that have no direct relation with living orders of insects. Their interrelationships are not at all well understood, and the greater number of them are grouped into a class, Palæodictyoptera, which serves rather as a dumping-ground than as the expression of an understood classification. Blattoid forms are numerous, and of great variety, their specialization having proceeded far beyond a primitive condition.

In answer to Mr. Dixon, the Author said that the Wellington Blattoid had the same degree of specialization as the two species compared with it from Liévin. It was, indeed, very closely related to them, much more so than to any British species yet known. A similar degree of specialization and relationship had been established between *Soomylacris deanensis* of the Forest of Dean Coalfield, *S. burri* of the Kent Coalfield, and *S. lievinensis* from the insect-beds of Liévin. Similarly, *Meganeura* (*Boltonites*, Handlirsch) *radstockensis* was closely related to *M. monyi* of the Coal Measures of Commentry.

4. *The* Ecology *of the* Westphalian *and the* Lower Part *of the* Staffordian Series *of* Clydach Vale *and* Gilfach Goch (East Glamorgan). By David Davies, F.G.S. (Read November 17th, 1920.)

[Plate II.]

Contents.

I. Introduction.

The evidence collected for this paper was obtained from the shales overlying the different seams of coal worked at Clydach Vale and Gilfach Goch.

As a result of 25 years' close examination of the plant-remains in an extensive collection of fossils from the shales in the Westphalian and the lower portion of the Staffordian Series (commonly known in South Wales as the 'Lower Coal Measures'), it was decided to compile a strict record of their distribution. The extent of roadways open for examination amounted to 60 miles at Clydach Vale, and 20 miles at Gilfach Goch, and these roadways gave access to the nine different seams of coal. The evidence for the tenth horizon was collected from the spoils brought out of the Abergorky Colliery, Blaenclydach. The shales overlying the several seams of coal were closely examined *in situ* for all the evidence that they might contain, and they were afterwards sent to the surface for a further and closer examination. Here each slab of shale was split into small fragments, in order to obtain an exact record of the number of plants in each block. A considerable variation in this number was observed.

Specimens of the plants were set apart to form a separate collection relative to each horizon. In this manner, 2500 specimens were brought together, representing 45,000 plants which had been recorded in the field for ecological purposes. Prior to the method of investigation just described, 1500 specimens of plants possessing some real value were brought home, thus bringing the number of specimens in the collection up to 4000. I am indebted to

Dr. Marie C. Stopes for advice as to the system of record which I adopted.

The following are the seams in ascending order :—

Five-Foot Seam.
Middle Yard Seam.
Upper Yard (or Bute) Seam.
Nine-Foot Seam.
Six-Foot Seam.
Two-Foot Nine Seam.
Pentre Seam.
Abergorky Seam.
No. 3 Rhondda Seam.
No. 2 Rhondda Seam.

The distribution of the plants was, in the first instance, recorded in alphabetical tables—A^1–Z^1, A^2–Z^2, A^3–Z^3, A^4–Z^4—which I have preserved for reference, if required. The results are embodied in Tables I–X (pp. 34–52), from which all the plants collected from each horizon are shown by means of a chart with their distribution within each class. The above-mentioned horizons have been examined in this area in the course of working out the ecology.

In every case the beds of fossiliferous shales were located in the roof over the roadways, and afterwards sent to the surface for examination, where the different genera of plants found in the blocks were determined.

The relation of each genus to the assemblage of genera of plants at any given horizon is shown by a large graph (Pl. II), drawn to scale and based upon the number of plants.

I wish to thank Dr. R. Kidston and Dr. Marie Stopes for the valuable monographs which they have from time to time kindly forwarded to me: I have found these of great assistance; and I wish also to thank Principal Trow and Prof. A. H. Cox for suggestions as to the arrangement of this paper.

I give below a short list of the literature, most of the works enumerated in which I have consulted:—

R. H. Goode. 'On the Fossil Flora of the Pembrokeshire Portion of the South Wales Coalfield' Q. J. G. S. vol. lxix (1913) pp. 252–76.

R. Kidston. 'Fossil Flora of the South Wales Coalfield, & the Relationship of its Strata to the Somerset & Bristol Coalfield' Trans. Roy. Soc. Edinb. vol. xxxvii (1894) pp. 565–614.

R. Kidston. 'On the Fossil Flora of the Yorkshire Coalfield (Second Paper)' *Ibid.* vol. xxxviii (1897) pp. 33–62.

R. Kidston. 'Contribution to our Knowledge of British Palæozoic Plants: Part i—Fossil Plants from the Scottish Coal Measures' *Ibid.* vol. li (1916) pp. 709–20.

R. Kidston. 'Fossil Flora of the Staffordshire Coalfield' *Ibid.* vol. li (1916) pp. 73–190.

R. Kidston. 'Fossil Plants of the Forest of Wyre & the Titterstone-Clee Hill Coalfields' *Ibid.* vol. li (1917) pp. 199–208.

R. Kidston. 'Les Végétaux Houillers recueillis dans le Hainaut Belge' Mém. Mus. R. Hist. Nat. Belg. vol. iv (1911) p. 268.

R. Kidston & W. J. Jongmans. 'A Monograph of the Calamites of Western Europe' 1917, p. 207.

W. E. Logan. Trans. Geol. Soc. ser. 2, vol. vi (1842) pp. 491–97.

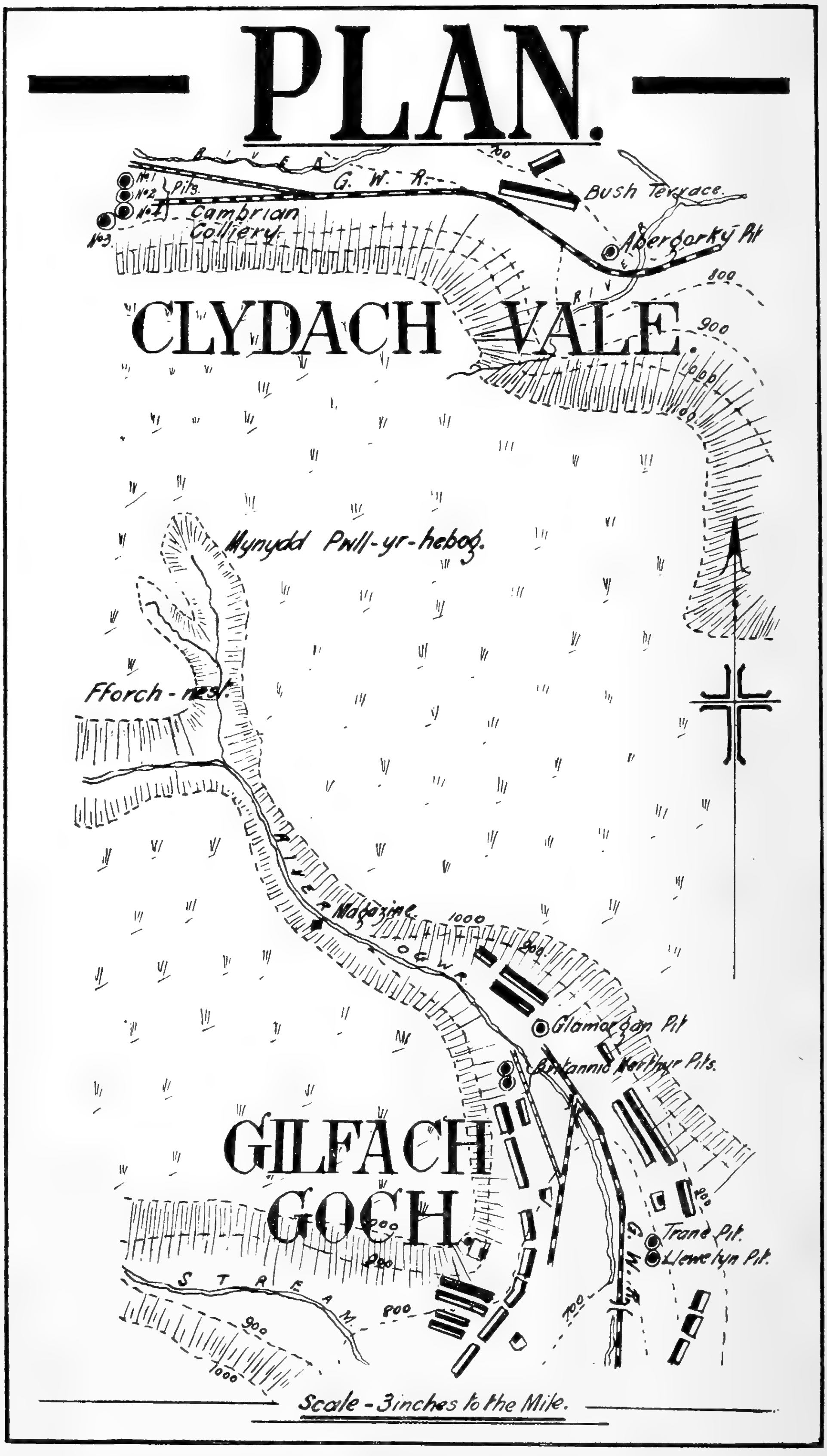
Starling Benson. Rep. Brit. Assoc. 1848, Trans. p. 64.

D. H. Scott. 'Studies in Fossil Botany' 2nd Edition. 1909.

A. C. Seward. 'Fossil Plants' vols. i–iii. 1898–1917.

Marie C. Stopes. 'The Fern Ledges: Carboniferous Flora of St. John (New Brunswick)' Mem. Geol. Surv. Canada, No. 41 (Geol. Ser. 38), 1914, p. 167.

Fig. 1.



PLAN.
River
G. W. R.
Bush Terrace.
No 1
No 2
No 4
No 3
Pits.
Cambrian Colliery
Aberdorky Pit
River
800
900
1000
CLYDACH VALE.
Mynydd Pwll-yr-hebog.
Fforch-nest.
River
Magazine.
1000
900
Glamorgan Pit
Britannic Merthyr Pits.
GILFACH GOCH
Trane Pit.
Llewelyn Pit.
G. W. R.
Stream.
800
900
1000
700
Scale - 3 inches to the Mile.

II. Ecology.

The following ten charts (figs. 2–11, pp. 35–53) show for each one of the ten seams:—

(a) The proportion of the genera within each class.

(b) The relative proportions of the various classes.

The data upon which each chart is based are set forth in corresponding Tables (I–X). These Tables show the distribution of the different genera of plants within a class, giving the horizon, locality, and number of blocks of shale in each alphabet, A^1 to Z^1; A^2 to Z^2; A^3 to Z^3; A^4 to Z^4: also the total result obtained in each class from A^1 to Z^4. Certain remarks on the floral assemblages of each seam are appended (pp. 33, 54–57).

The Five-Foot Seam (Table I & fig. 2, pp. 34–35) lies immediately above the Millstone Grit at the Britannic Colliery, Gilfach Goch, and is the lowest seam found in this particular area; but at Clydach Vale another seam, known as the Gelli Deg, occurs 30 feet below the Five-Foot Seam. The shales for examination were obtained in different directions from the shaft, that is, south-south-west, north-north-west, and east, the maximum distance in this area from south-south-west to east being 4000 yards. The position of the shale-beds above the coal-seam varied from 3 to 15 feet. Layers of dark and grey shale were obtained from each area. The dark shales always proved to be the more fossiliferous.

Calamites dominated among the plants belonging to the Class Equisetales. Not a single specimen of *Sphenophyllum* was found. Lycopodiales were almost absent. Among the ferns and fernlike plants, *Alethopteris* was more numerous than any other genus, except that in blocks A^2–Z^2, *Neuropteris* was the commonest form. All other blocks, that is, A^1–Z^1, A^3–Z^3, and A^4–Z^4, showed the predominance of *Alethopteris*. A significant fact here is the predominance of this form, and then its sudden, almost complete disappearance. It is only of rare occurrence in the overlying horizons.

Cordaite-leaves were found in great numbers, and were commonly associated with *Calamites* on the slabs of shale. No seeds belonging to *Cordaites* were observed.

Taking the different classes into consideration, plants belonging to the Cordaitales were the dominant forms. Here again, it is well to mention that this horizon alone yields Cordaitales in greater number than plants of other classes.

The Middle Yard Seam (Table II & fig. 3, pp. 36–37) is found in the shaft of the Britannic Colliery, 75 feet above the Five-Foot Seam. The shales for examination were obtained from two positions, areas north-east and south-west, which are 2500 yards apart.

The shales overlying the seam, for some 8 to 10 feet in thickness,

TABLE I.

Different Classes.	A^1 to Z^1.	A^2 to Z^2.	A^3 to Z^3.	A^4 to Z^4.	A^1 to Z^4.
	FIVE-FOOT SEAM, BRITANNIC COLLIERY, GILFACH GOCH.				
	Blocks of Shale = 26 Total Plants =452	Blocks of Shale = 26 Total Plants =534	Blocks of Shale = 26 Total Plants =328	Blocks of Shale = 26 Total Plants =517	Blocks of Shale examined = 104 Total Plants recorded =1831
Equisetales. 562 Plants =30·69 p. c.	*Calamites* 67·62 p. c. *Asterophyllites* 19·05 p. c. *Myrophyllites* 13·33 p. c.	*Calamites* 61·76 p. c. *Asterophyllites* 35·29 p. c. *Annularia* 0·99 p. c. Calamite-cones 1·96 p. c.	*Calamites* 46·50 p. c. *Asterophyllites* 25·30 p. c. *Calamocladus* 4·80 p. c. Calamite-leaves 19·20 p. c. *Myrophyllites* 4·20 p. c.	*Calamites* 42·05 p. c. *Asterophyllites* 30·00 p. c. *Calamocladus* 5·60 p. c. *Annularia* 3·65 p. c. *Myrophyllites* 18·70 p. c.	*Calamites* 55·16 p. c. *Asterophyllites* 28·64 p. c. *Calamocladus* 2·31 p. c. *Annularia* 1·07 p. c. Calamite-leaves 4·96 p. c. Calamite-cones 0·74 p. c. *Myrophyllites* 7·12 p. c.
Sphenophyllales.	—	—	—	—	—
Lycopodiales. 4 Plants=0·22 p. c.	— —	— —	*Lepidodendron* ....1 *Sigillaria* 1	*Lepidodendron*...... .....2 —	*Lepidodendron* 75 p. c. *Sigillaria* 25 p. c.
Filicales and Pteridosperms. 453 Plants =24·74 p. c.	*Alethopteris* 36·64 p. c. *Neuropteris* 16·40 p. c. *Mariopteris* 12·30 p. c. (Rachis of Ferns or Fern-like plants) 9·90 p. c. *Sphenopteris* 22·30 p. c. *Cyclopteris* (scale-leaves) 1·64 p. c. Seeds ? ... 0·82 p. c.	*Alethopteris* 34·18 p. c. *Neuropteris* 43·67 p. c. *Mariopteris* 7·41 p. c. (Rachis of Ferns or Fern-like plants) 12·03 p. c. *Sphenopteris* 0·72 p. c. *Cyclopteris* (scale-leaves) 1·27 p. c. Seeds ... 0·72 p. c.	*Alethopteris* 57·57 p. c. *Neuropteris* 18·19 p. c. — (Rachis of Ferns or Fern-like plants) 15·15 p. c. — *Cyclopteris* (scale-leaves) 3·03 p. c. Seeds ... 6·06 p. c.	*Alethopteris* 47·14 p. c. *Neuropteris* 13·59 p. c. *Mariopteris* 2·85 p. c. (Rachis of Ferns or Fern-like plants) 23·57 p. c. *Sphenopteris* 7·85 p. c. *Cyclopteris* 2·14 p. c. Seeds ... 2·86 p. c.	*Alethopteris* 40·39 p. c. *Neuropteris* 25·16 p. c. *Mariopteris* 6·84 p. c. (Rachis of Ferns or Fern-like plants) 15·21 p. c. *Sphenopteris* 8·83 p. c. *Cyclopteris* 1·785 p. c. Seeds ... 1·785 p. c.
Cordaitales. 812 Plants =44·35 p. c.	Cordaite-leaves.........225	Cordaite-leaves 172	Cordaite-leaves ....145 Pithcast : *Sternbergia* 2	Cordaite-leaves 268	Cordaite-leaves 810=44·20 p. c. Pithcast : *Sternbergia* 2=0·15 p. c.

Fig. 2.

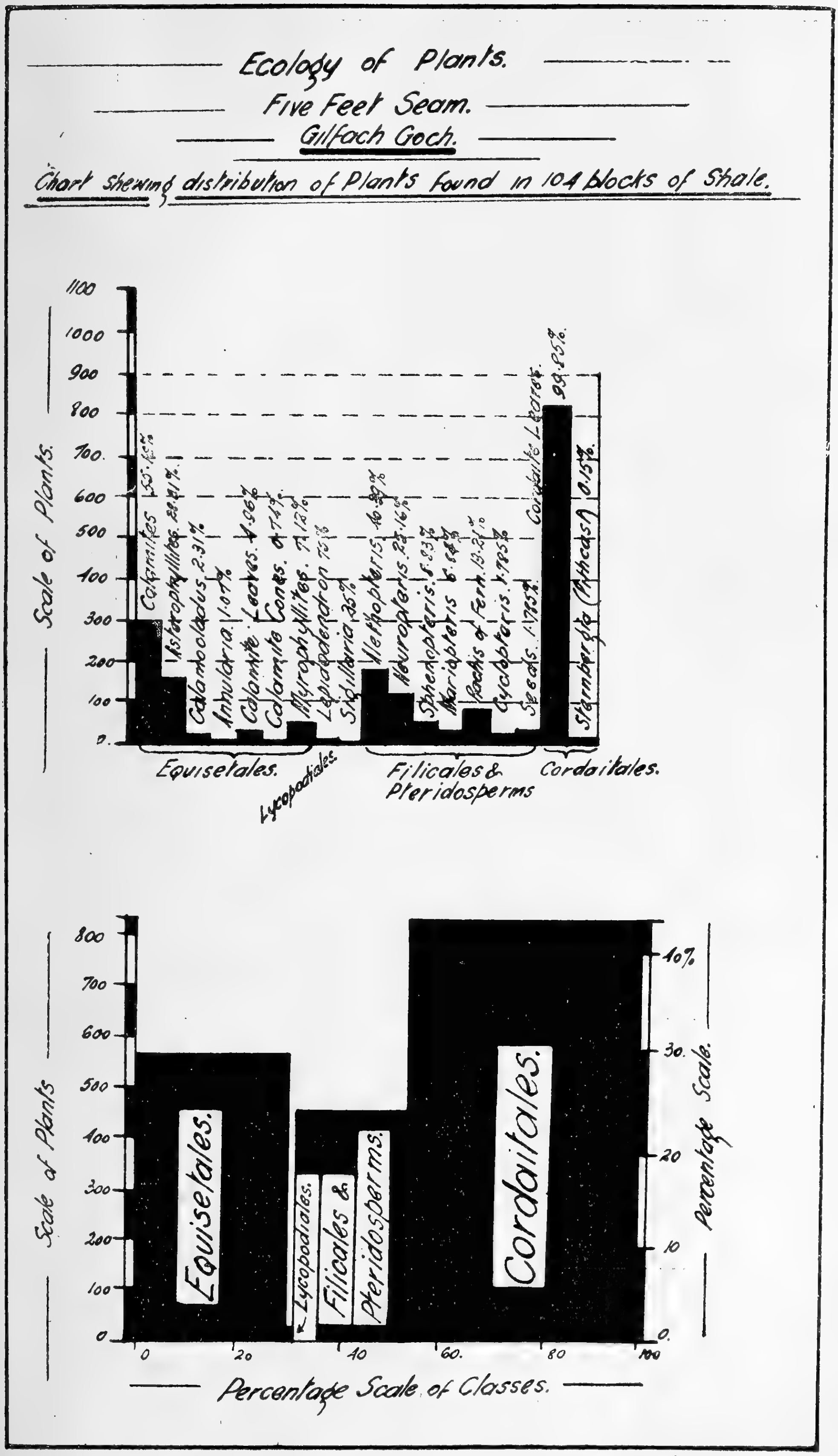
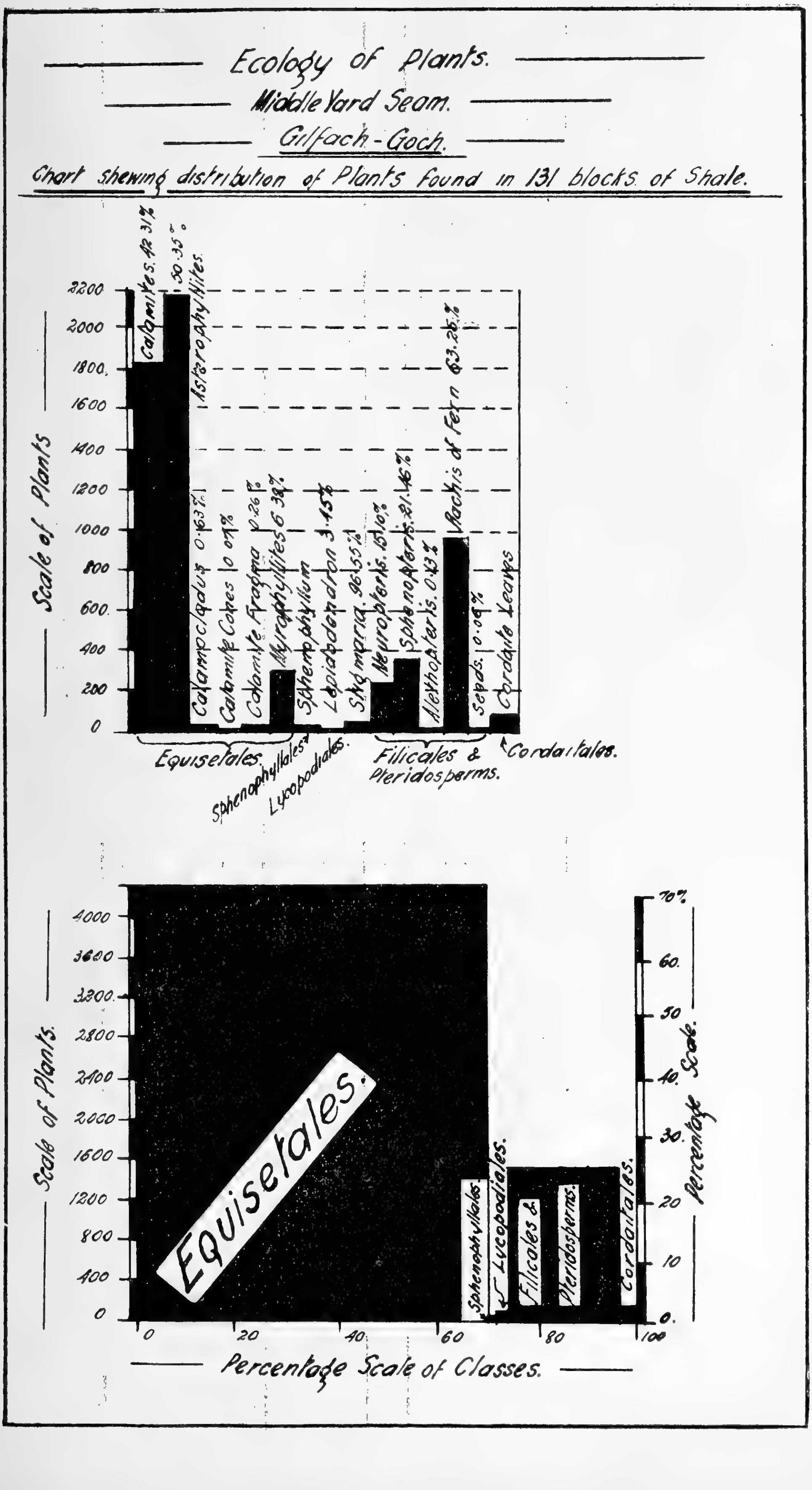

Ecology of Plants.
Five Feet Seam.
Gilfach Goch.
Chart shewing distribution of Plants found in 104 blocks of Shale.
Scale of Plants.
Equisetales.
Lycopodiales.
Filicales & Pteridosperms
Cordaitales.
Scale of Plants
Equisetales.
Lycopodiales.
Filicales & Pteridosperms.
Cordaitales.
Percentage Scale.
Percentage Scale of Classes.

TABLE II.

Different Classes.	A^1 to Z^1.	A^2 to Z^2.	A^3 to Z^3.	A^4 to Z^4.	A^1 to Z^4.
	MIDDLE YARD SEAM, BRITANNIC COLLIERY, GILFACH GOCH.				
	Blocks of Shale = 48 Total Plants =1441	Blocks of Shale = 31 Total Plants =1467	Blocks of Shale = 26 Total Plants =1360	Blocks of Shale = 26 Total Plants =1678	Blocks of Shale examined = 131 Total Plants recorded =5946
Equisetales. 4292 Plants =72·19 p. c.	*Calamites* 47·30 p. c. *Asterophyllites* 43·35 p. c. *Calamocladus* 0·82 p. c. Calamite-cones 0·27 p. c. Calamite-phragma 0·18 p. c. *Myrophyllites* 8·08 p. c.	*Calamites* 44·74 p. c *Asterophyllites* 46·5 p. c. *Calamocladus* 0·64 p. c. — Calamite-phragma 0·20 p. c. *Myrophyllites* 7·92 p. c.	*Calamites* 42·90 p. c. *Asterophyllites* 50·53 p. c. *Calamocladus* 0·29 p. c. — Calamite-phragma 0·39 p. c. *Myrophyllites* 5·89 p. c.	*Calamites* 32·62 p. c. *Asterophyllites* 63·42 p. c. *Calamocladus* 0·75 p. c. — Calamite-phragma 0·21 p. c. *Myrophyllites* 3·00 p. c.	*Calamites* 42·31 p. c. *Asterophyllites* 50·35 p. c. *Calamocladus* 0·63 p. c. Calamite-cones 0·07 p. c. Calamite-phragma 0·26 p. c. *Myrophyllites* 6·38 p. c.
Sphenophyllales. 11 Plants =0·19 p. c.	—	*Sphenophyllum* 8	—	*Sphenophyllum* 3	*Sphenophyllum* 11
Lycopodiales. 29 Plants =0·49 p. c.	*Lepidodendron* ....1 *Stigmaria* 28	— —	— —	— —	*Lepidodendron* 3·45 p. c. *Stigmaria* 96·55 p. c.
Filicales and Pteridosperms. 1536 Plants =25·83 p. c.	*Neuropteris* 38·43 p. c. *Sphenopteris* 17·91 p. c. — Rachis of Ferns or Fern-like plants 43·66 p. c. —	*Neuropteris* 14·71 p. c. *Sphenopteris* 19·79 p. c. — Rachis of Fern 65 p. c. Seeds? ... 0·50 p. c.	*Neuropteris* 8·13 p. c. *Sphenopteris* 15·96 p. c. *Alethopteris* 0·60 p. c. Rachis of Fern 75·31 p. c. Seeds ... —	*Neuropteris* 9·88 p. c. *Sphenopteris* 25·84 p. c. — Rachis of Fern 64·28 p. c. —	*Neuropteris* 15·10 p. c. *Sphenopteris* 21·46 p. c. *Alethopteris* 0·13 p. c. Rachis of Ferns or Fern-like plants 63·25 p. c. Seeds? ... 0·06 p. c.
Cordaitales. 78 Plants =1·30 p. c.	Cordaite-leaves 53	Cordaite-leaves 17	Cordaite-leaves 7	Cordaite-leaves 1	Cordaite-leaves 78

Fig. 3.

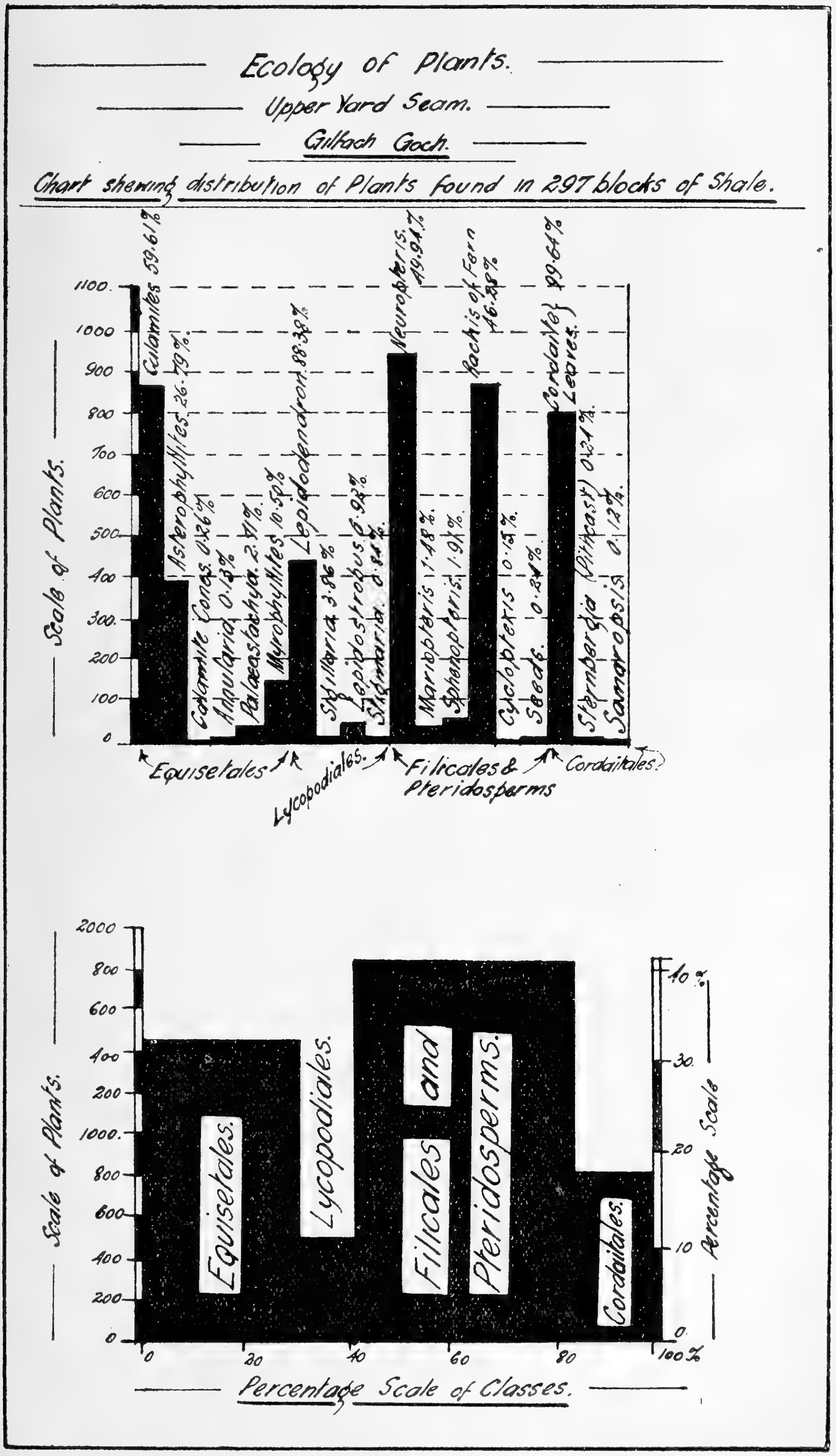


Ecology of Plants.
Middle Yard Seam.
Gilfach-Goch.
Chart shewing distribution of Plants found in 131 blocks of Shale.
Scale of Plants
2200
2000
1800.
1600
1400
1200
1000
800
600.
400
200
0
Calamites. 42.31%
50.35%
Asterophyllites.
Calamocladus 0.163%
Calamite Cones 0.07%
Calamite Fragma 0.26%
Myriophyllites 6.38%
Sphenophyllum
Lepidodendron 3.45%
Stigmaria. 96.55%
Neuropteris. 15.10%
Sphenopteris. 21.46%
Alethopteris. 0.43%
Rachis of Fern 63.26%
Seeds. 0.09%
Cordaite Leaves
Equisetales.
Sphenophyllales &
Lycopodiales.
Filicales &
Pteridosperms.
Cordaitales.
Scale of Plants.
4000
3600
3200.
2800
2400
2000
1600
1200
800
400
0
Equisetales.
Sphenophyllales
Lycopodiales.
Filicales &
Pteridosperms.
Cordaitales.
70%
60.
50
40.
30.
20
10
0.
Percentage Scale.
0
20
40
60
80
100
Percentage Scale of Classes.

Table III.

Different Classes.	A¹ to Z¹.	A² to Z².	A³ to Z³.	A⁴ to Z⁴.	A¹ to Z⁴.
	Upper Yard Seam, Britannic Colliery, Gilfach Goch.				
	Blocks of Shale = 83 Total Plants =1256	Blocks of Shale = 77 Total Plants =1140	Blocks of Shale = 63 Total Plants =1187	Blocks of Shale = 74 Total Plants =1056	Blocks of Shales examined = 297 Total Plants recorded =4639·
Equisetales. 1452 Plants =31·30 p. c.	*Calamites* 73·73 p. c. *Asterophyllites* 18·08 p. c. —— —— —— *Myrophyllites* 8·19 p. c.	*Calamites* 52·20 p. c. *Asterophyllites* 28·11 p. c. —— —— —— *Myrophyllites* 19·69 p. c.	*Calamites* 29 23 p. c. *Asterophyllites* 46·37 p. c. *Annularia* 0·40 p. c. Calamite-cones 8·06 p. c. *Palæostachya* 0·80 p. c. *Myrophyllites* 15·14 p. c.	*Calamites* 92·63 p. c. *Asterophyllites* 7·08 p. c. —— —— —— *Myrophyllites* 0·29 p. c.	*Calamites* 59·61 p. c. *Asterophyllites* 26·79 p. c. *Annularia* 0·13 p. c. Calamite-cones 0·26 p. c. *Palæostachya* 2·71 p. c. *Myrophyllites* 10·50 p. c.
Sphenophyllales.	——	——	——	——	——
Lycopodiales. 491 Plants =10·59 p. c.	—— *Sigillaria* 60 p. c. *Lepidostrobus* 20 p. c. *Stigmaria* 20 p. c.	—— —— —— ——	*Lepidodendron* 29·41 p. c. *Sigillaria* 41·18 p. c. *Lepidostrobus* 29·41 p. c. ——	*Lepidodendron* 94·31 p. c. *Sigillaria* —— *Lepidostrobus* 5·69 p. c. *Stigmaria* ——	*Lepidodendron* 88·38 p. c. *Sigillaria* 3·86 p. c. *Lepidostrobus* 6·92 p. c. *Stigmaria* 0·84 p. c.
Filicales and Pteridosperms. 1884 Plants =40·61 p. c.	*Neuropteris* 44·94 p. c. *Sphenopteris* 1·23 p. c. *Mariopteris* 2·18 p. c. Rachis of Fern 51·60 p. c. *Cyclopteris* 0·05 p. c. ——	*Neuropteris* 8·95 p. c. —— *Mariopteris* 0·76 p. c. Rachis of Fern 50·23 p. c. *Cyclopteris* 0·06 p. c. ——	*Neuropteris* 59·67 p. c. *Sphenopteris* 5·35 p. c. *Mariopteris* 1·44 p. c. Rachis of Fern 32·51 p. c. *Cyclopteris* 0·20 p. c. Seeds ... 0 83 p. c.	*Neuropteris* 23·07 p. c. *Sphenopteris* 7·69 p. c. —— Rachis of Fern 69·24 p. c. —— ——	*Neuropteris* 49·94 p. c. *Sphenopteris* 1·91 p. c. *Mariopteris* 1·48 p. c. Rachis of Ferns or Fern-like plants 46·28 p. c. *Cyclopteris* 0·15 p. c. Seeds ... 0·24 p. c.
Cordaitales. 812 Plants =17·50 p. c.	Cordaite-leaves 150	Cordaite-leaves 238	Cordaite-leaves ....187 Pithcast : *Sternbergia* 1	Cordaite-leaves ....234 Pithcast : *Sternbergia* 1 *Samaropsis* 1	Cordaite-leaves 99·64 p. c. Pithcast : *Sternbergia* 0·24 p. c. *Samaropsis* ... 0·12 p. c.

Fig. 4.

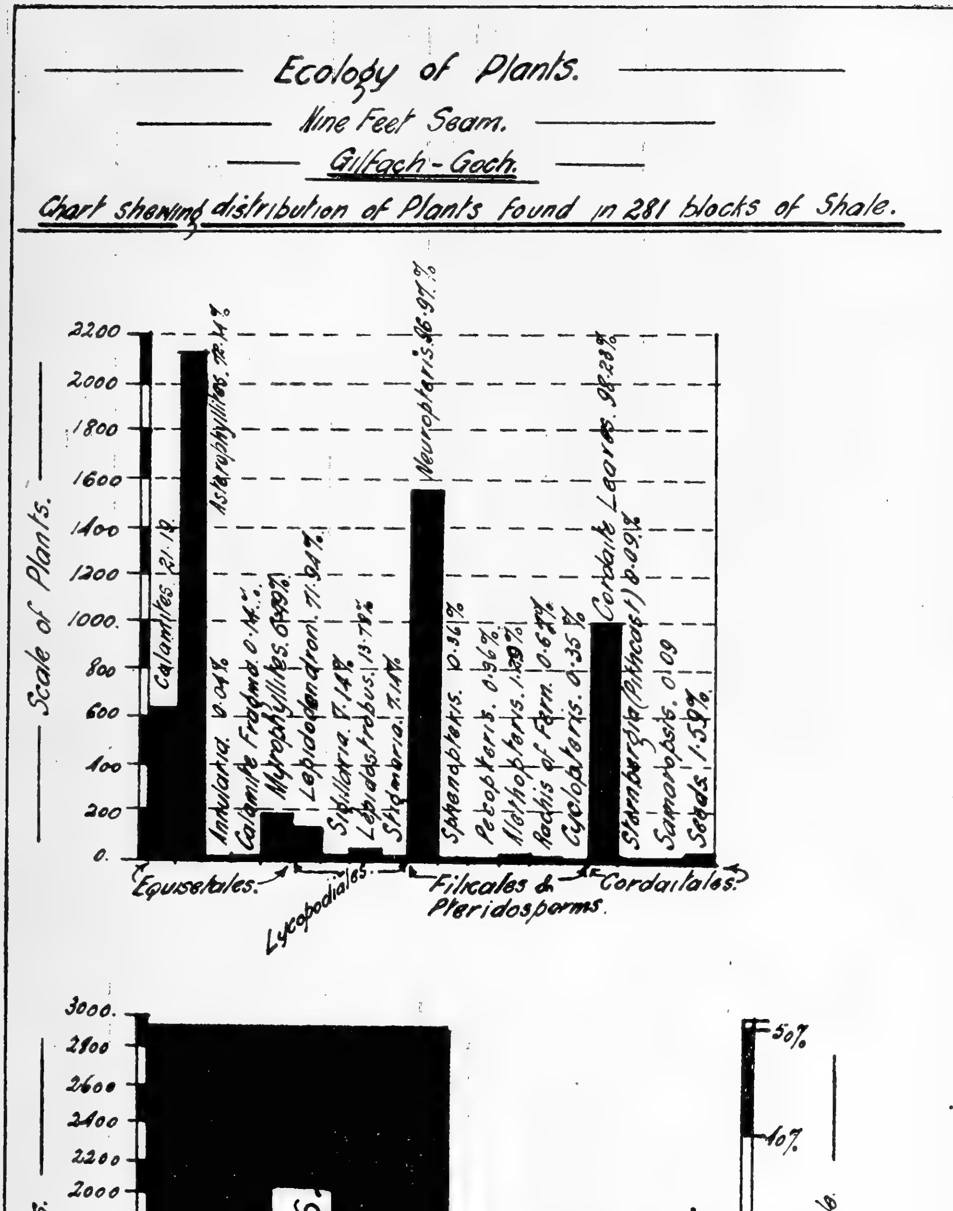


Ecology of Plants.
Upper Yard Seam.
Gilfach Goch.
Chart shewing distribution of Plants found in 297 blocks of Shale.
Scale of Plants.
Calamites 59.61%
Asterophyllites 26.79%
Lepidodendron 88.38%
Neuropteris 49.91%
Rachis of Fern 46.38%
Cordaites Leaves 99.64%
Equisetales
Lycopodiales.
Filicales & Pteridosperms
Cordaitales.
Equisetales.
Lycopodiales.
Filicales and Pteridosperms.
Cordaitales.
Percentage Scale
Percentage Scale of Classes.

Table IV.

Different Classes.	A^1 to Z^1.	A^2 to Z^2.	A^3 to Z^3.	A^4 to Z^4.	A^1 to Z^4.
	Nine-Foot Seam, Trane Colliery, Gilfach Goch.				
	Blocks of Shale = 120 Total Plants =1467	Blocks of Shale = 57 Total Plants =1230	Blocks of Shale = 54 Total Plants =1442	Blocks of Shale = 50 Total Plants =1606	Blocks of Shale examined = 281 Total Plants recorded =5745
Equisetales. 2926 Plants =50·93 p. c.	*Calamites* 18·45 p. c. *Asterophyllites* 72·60 p. c. *Annularia* 0·17 p. c. — *Myrophyllites* 8·78 p. c.	*Calamites* 19·60 p. c. *Asterophyllites* 75·08 p. c. *Annularia* — Calamite-phragma 0·34 p. c. *Myrophyllites* 4·98 p. c.	*Calamites* 20·22 p. c. *Asterophyllites* 71·17 p. c. — Calamite-phragma 0·14 p. c. *Myrophyllites* 8·47 p. c.	*Calamites* 24·40 p. c. *Asterophyllites* 70·85 p. c. — Calamite-phragma 0·11 p. c. *Myrophyllites* 4·64 p. c.	*Calamites* 21·19 p. c. *Asterophyllites* 72·14 p. c. *Annularia* 0·04 p. c. Calamite-phragma 0·14 p. c. *Myrophyllites* 6·49 p. c.
Sphenophyllales.	—	—	—	—	—
Lycopodiales. 196 Plants =3·41 p. c.	*Lepidodendron* 68·47 p. c. *Sigillaria* 2·17 p. c. *Lepidostrobus* 14·13 p. c. *Stigmaria* 15·23 p. c.	*Lepidodendron* 81·26 p. c. *Sigillaria* 9·37 p. c. *Lepidostrobus* 9·37 p. c. —	*Lepidodendron* 65 p. c. *Sigillaria* 20 p. c. *Lepidostrobus* 15 p. c —	*Lepidodendron* 75 p. c. *Sigillaria* 9·61 p. c. *Lepidostrobus* 15·39 p. c. —	*Lepidodendron* 71·94 p. c. *Sigillaria* 7·14 p. c. *Lepidostrobus* 13·78 p. c. *Stigmaria* 7·14 p. c.
Filicales and Pteridosperms. 1621 Plants =28·19 p. c.	*Neuropteris* 95·41 p. c. *Mariopteris* — *Sphenopteris* 0·96 p. c. *Pecopteris* 1·22 p. c. *Alethopteris* 1·69 p. c. Rachis of Fern 0·24 p. c. *Cyclopteris* 0·48 p. c.	*Neuropteris* 99·08 p. c. — — *Pecopteris* 0·23 p. c. *Alethopteris* 0·23 p. c. Rachis of Fern 0·46 p. c. —	*Neuropteris* 98·29 p. c. — — — *Alethopteris* 0·86 p. c. Rachis of Fern 0·61 p. c. *Cyclopteris* 0·21 p. c.	*Neuropteris* 94·09 p. c. — *Sphenopteris* 0·65 p. c. — *Alethopteris* 2·95 p. c. Rachis of Fern 1·66 p. c. *Cyclopteris* 0·65 p. c.	*Neuropteris* 96·97 p. c. — *Sphenopteris* 0·36 p. c. *Pecopteris* 0·36 p. c. *Alethopteris* 1·29 p. c. Rachis of Ferns or Fern-like plants 0·67 p. c. *Cyclopteris* 0·35 p. c.
Cordaitales. 1002 Plants =17·47 p. c.	Cordaite-leaves 98·94 p. c. — *Samaropsis* 0·26 p. c. Seeds? ... 0·80 p. c.	Cordaite-leaves 98·75 p. c. Pithcast : *Sternbergia* 0·62 p. c. — Seeds ... 0·63 p. c.	Cordaite-leaves 98·66 p. c. — — Seeds ... 1·34 p. c.	Cordaite-leaves 96·16 p. c. — — Seeds ... 3·84 p. c.	Cordaite-leaves 98·23 p. c. Pithcast : *Sternbergia* 0·09 p. c. *Samaropsis* 0·09 p. c. Seeds ... 1·59 p. c.

Fig. 5.

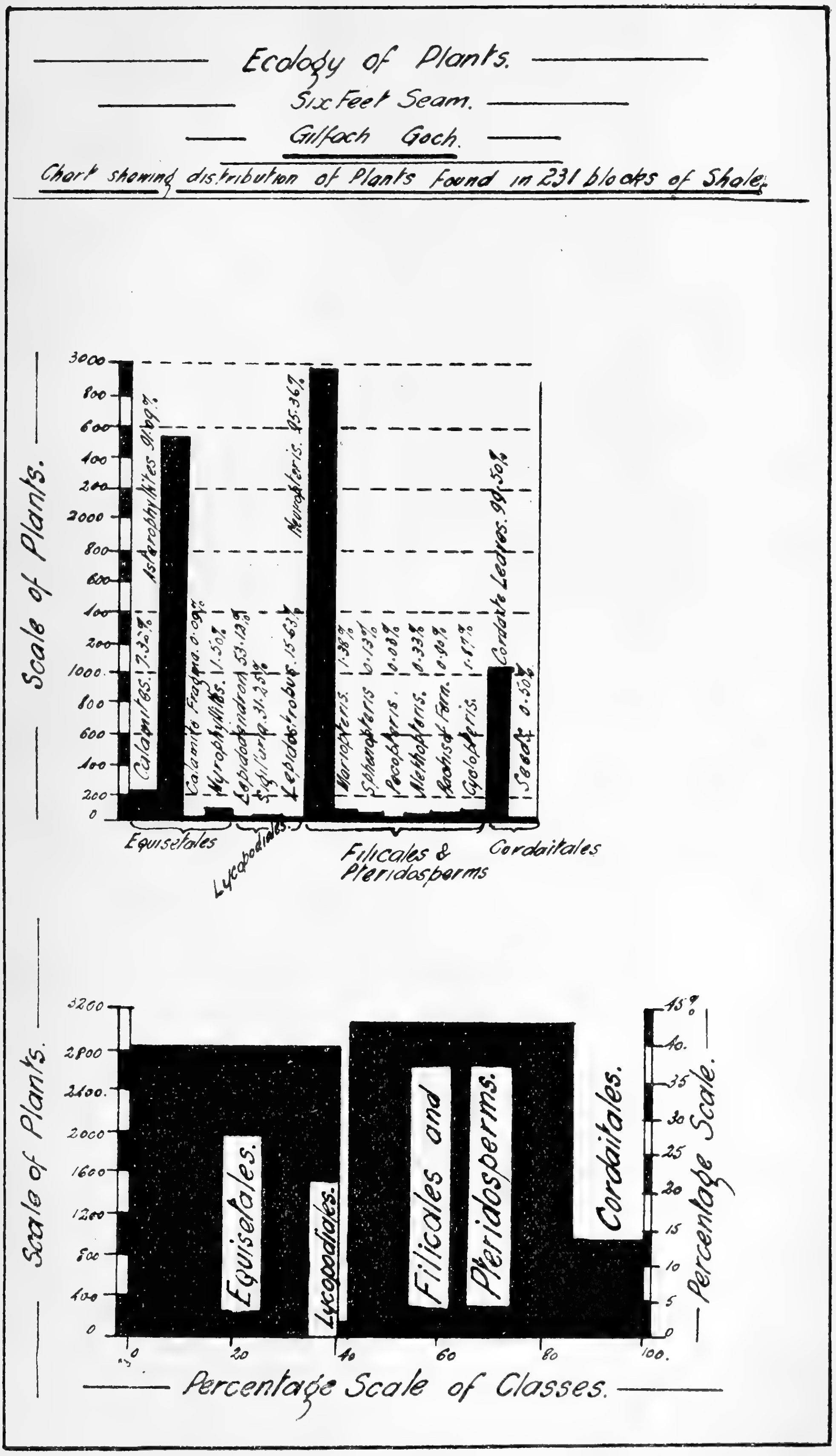


Ecology of Plants.
Nine Feet Seam.
Gilfach-Goch.
Chart showing distribution of Plants found in 281 blocks of Shale.
Scale of Plants.
2200
2000
1800
1600
1400
1200
1000.
800
600
400
200
0.
Calamites 21.19
Asterophyllites 77.14%
Annularia 0.04%
Calamite Fragmd. 0.14%
Lepidodendron 71.94%
Sigillaria 7.14%
Stigmaria 7.14%
Neuropteris 86.97%
Sphenopteris 0.36%
Pecopteris 0.36%
Rachis of Fern 0.67%
Cyclopteris 0.35%
Cordaite Leaves 98.28%
Samaropsis 0.09
Seeds 1.59%
Equisetales.
Lycopodiales.
Filicales & Pteridosperms.
Cordaitales.
3000.
2800
2600
2400
2200
2000
1800
1600
1400
1200.
1000
800
600
400.
200
0
Equisetales.
Lycopodiales.
Filicales and Pteridosperms.
Cordaitales
50%
40%
30%
20.
10
0
Percentage Scale.
0
20
40
60
80
100%
Percentage Scale of Classes.

Table V.

Different Classes.	A^1 to Z^1.	A^2 to Z^2.	A^3 to Z^3.	A^4 to Z^4.	A^1 to Z^4.
	Six-Foot Seam, Trane Colliery, Gilfach Goch.				
	Blocks of Shale = 66 Total Plants =1589	Blocks of Shale = 55 Total Plants =1740	Blocks of Shale = 53 Total Plants =1861	Blocks of Shale = 57 Total Plants =1814	Blocks of Shale examined = 231 Total Plants recorded =7004
Equisetales. 2854 Plants =40·75 p. c.	*Calamites* 9·84 p. c. *Asterophyllites* 88·53 p. c. Calamite-phragma 0·29 p. c. *Myrophyllites* 1·34 p. c.	*Calamites* 10·38 p. c. *Asterophyllites* 87·67 p. c. —— *Myrophyllites* 1·95 p. c.	*Calamites* 3·48 p. c. *Asterophyllites* 94·01 p. c. —— *Myrophyllites* 2·51 p. c.	*Calamites* 5·73 p. c. *Asterophyllites* 93·99 p. c. —— *Myrophyllites* 0·28 p. c.	*Calamites* 7·32 p. c. *Asterophyllites* 91·09 p. c. Calamite-phragma 0·09 p. c. *Myrophyllites* 1·50 p. c.
Sphenophyllales.	——	——	——	——	——
Lycopodiales. 32 Plants =0·45 p. c.	*Lepidodendron* 60 p. c. *Sigillaria* 40 p. c. *Lepidostrobus* ——	*Lepidodendron* 80 p. c. *Sigillaria* 20 p. c. ——	*Lepidodendron* 42·85 p. c. *Sigillaria* 35·71 p. c. *Lepidostrobus* 21·44 p. c.	*Lepidodendron* 50 p. c. *Sigillaria* 25 p. c. *Lepidostrobus* 25 p. c.	*Lepidodendron* 53·12 p. c. *Sigillaria* 31·25 p. c. *Lepidostrobus* 15·63 p. c.
Filicales and Pteridosperms. 3107 Plants =44·36 p. c.	*Neuropteris* 93·84 p. c. *Mariopteris* 0·80 p. c. *Sphenopteris* 0·13 p. c. *Pecopteris* —— *Alethopteris* 0·54 p. c. Rachis of Ferns or Fern-like plants 2·14 p. c. *Cyclopteris* 2·55 p. c.	*Neuropteris* 96·50 p. c. *Mariopteris* 1·73 p. c. *Sphenopteris* —— *Pecopteris* —— *Alethopteris* 0·54 p. c. Rachis of Ferns or Fern-like plants 0·27 p. c. *Cyclopteris* 0·96 p. c.	*Neuropteris* 97·03 p. c. *Mariopteris* 1·30 p. c. *Sphenopteris* 0·24 p. c. *Pecopteris* 0·12 p. c. *Alethopteris* 0·12 p. c. Rachis of Ferns or Fern-like plants 0·24 p. c. *Cyclopteris* 0·95 p. c.	*Neuropteris* 94·08 p. c. *Mariopteris* 1·67 p. c. *Sphenopteris* 0·13 p. c. —— *Alethopteris* 0·13 p. c. Rachis of Ferns or Fern-like plants 1·04 p. c. *Cyclopteris* 2·95 p. c.	*Neuropteris* 95·36 p. c. *Mariopteris* 1·38 p. c. *Sphenopteris* 0·13 p. c. *Pecopteris* 0·03 p. c. *Alethopteris* 0·33 p. c. Rachis of Ferns or Fern-like plants 0·90 p. c. *Cyclopteris* 1·87 p. c.
Cordaitales. 1011 Plants =14·44 p. c.	Cordaite-leaves 98·73 p. c. Seeds ? ... 1·27 p. c.	Cordaite-leaves 99·26 p. c. Seeds ? ... 0·74 p. c.	Cordaite-leaves 99·6 p. c. Seeds ... 0·4 p. c.	Cordaite-leaves 100 p. c. ——	Cordaite-leaves 99·5 p. c. Seeds ? ... 0·5 p. c.

Fig. 6.



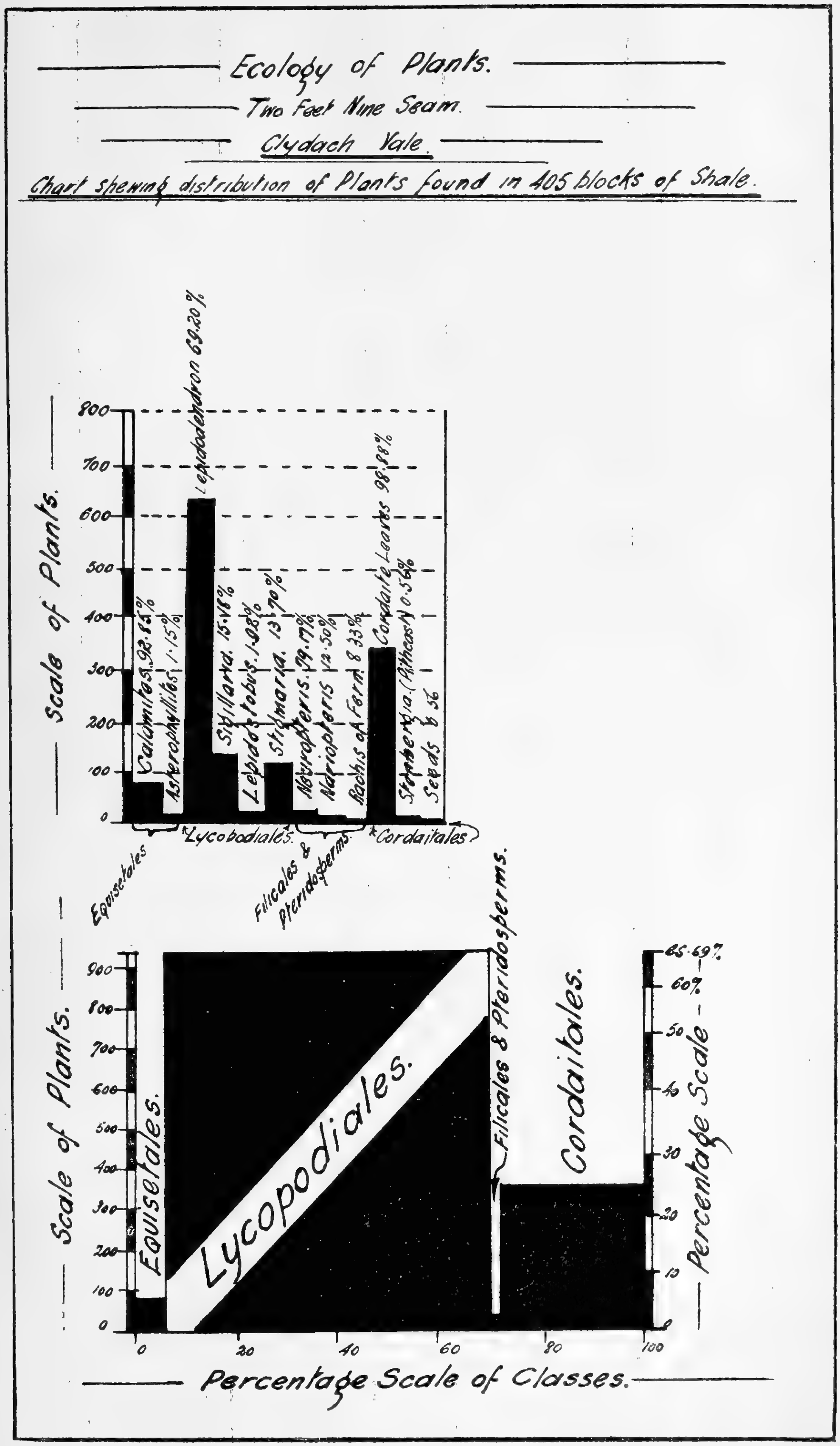
Ecology of Plants.
Six Feet Seam.
Gilfach Goch.
Chart showing distribution of Plants found in 231 blocks of Shale.
Scale of Plants.
Calamites. 7.32%
Asterophyllites 91.69%
Calamite Fragms. 0.09%
Myriophyllites. 1.50%
Lepidodendron 53.12%
Sigillaria 31.25%
Lepidostrobus 15.63%
Neuropteris. 95.36%
Mariopteris. 1.38%
Sphenopteris 0.13%
Pecopteris. 0.08%
Alethopteris. 0.33%
Rachis of Fern. 0.90%
Cyclopteris. 1.87%
Cordaite Leaves. 99.50%
Seeds 0.50%
Equisetales
Lycopodiales.
Filicales & Pteridosperms
Cordaitales
Scale of Plants.
Equisetales.
Lycopodiales.
Filicales and Pteridosperms.
Cordaitales.
Percentage Scale.
Percentage Scale of Classes.

Table VI.

Two-Foot Nine Seam, Cambrian Colliery, Clydach Vale.

One Class: A to Z.	A to Z.
	Blocks of Shale examined = 405
	Total Plants recorded =1402
Equisetales. 84 Plants =5·99 p. c.	*Calamites* .... 92·85 p. c.
	Asterophyllites .... 7·15 p. c.
Sphenophyllales.	—
Lycopodiales. 935 Plants =66·69 p. c.	*Lepidodendron* .... 69·2 p. c.
	Sigillaria .... 15·18 p. c.
	Lepidostrobus............ 1·92 p. c.
	Stigmaria .... 13·7 p. c.
Filicales and Pteridosperms. 24 Plants =1·71 p. c.	*Neuropteris* .... 79·17 p. c.
	Mariopteris............... 12·5 p. c.
	Rachis of Ferns or Fernlike plants...................... 8·33 p. c.
Cordaitales. 359 Plants =25·61 p. c.	Cordaite-leaves .... 98·88 p. c.
	Pithcast: *Sternbergia* 0·56 p. c.
	Seeds ? .... 0·56 p. c.

Fig. 7.

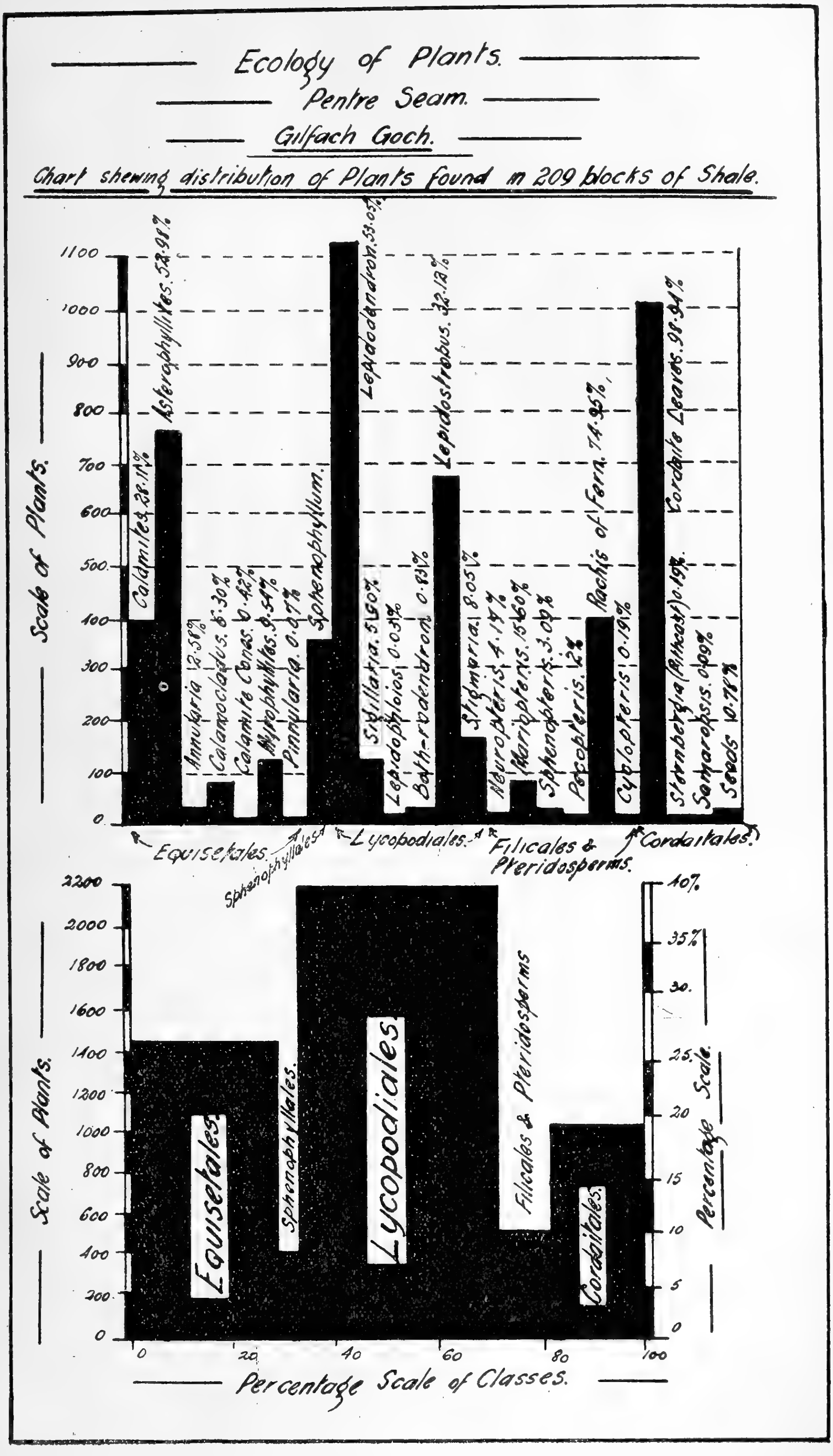


Ecology of Plants.
Two Feet Nine Seam.
Clydach Vale.
Chart shewing distribution of Plants found in 405 blocks of Shale.
Scale of Plants.
Calamites 92.85%
Asterophyllites 1.15%
Lepidodendron 69.20%
Sigillaria 15.18%
Lepidostrobus 1.98%
Stigmaria 13.70%
Neuropteris 79.17%
Mariopteris 12.50%
Rachis of Fern 8.33%
Cordaite Leaves 98.88%
Sternbergia (Pithcast) 0.56%
Seeds 0.56
Equisetales
Lycopodiales
Filicales & Pteridosperms
Cordaitales
Equisetales.
Lycopodiales.
Filicales & Pteridosperms.
Cordaitales.
Percentage Scale
Percentage Scale of Classes.

TABLE VII.

Different Classes.	A^1 to Z^1.	A^2 to Z^2.	A^3 to Z^3.	A^4 to Z^4.	A^1 to Z^4.
	PENTRE SEAM, TRANE COLLIERY, GILFACH GOCH.				
	Blocks of Shale = 50 Total Plants =1032	Blocks of Shale = 58 Total Plants =1389	Blocks of Shale = 47 Total Plants =1427	Blocks of Shale = 54 Total Plants =1697	Blocks of Shale examined = 209 Total Plants recorded =5545
Equisetales. 1444 Plants =26·04 p. c.	*Calamites* 21·91 p. c. *Asterophyllites* 68·50 p. c. *Annularia* 5·47 p. c. — Calamite-cones 4·12 p. c. *Myrophyllites* — *Pinnularia* —	*Calamites* 11·11 p. c. *Asterophyllites* 71·49 p. c. *Annularia* 1·47 p. c. *Calamocladus* 2·30 p. c. Calamite-cones — *Myrophyllites* 13·41 p. c. *Pinnularia* 0·22 p. c.	*Calamites* 30·61 p. c. *Asterophyllites* 52·29 p. c. *Annularia* 4·59 p. c. *Calamocladus* 5·12 p. c. Calamite-cones — *Myrophyllites* 7·39 p. c. —	*Calamites* 43·22 p. c. *Asterophyllites* 33·66 p. c. *Annularia* 1·59 p. c. *Calamocladus* 11·95 p. c. Calamite-cones 0·59 p. c. *Myrophyllites* 8·99 p. c. —	*Calamites* 28·11 p. c. *Asterophyllites* 52·98 p. c. *Annularia* 2·58 p. c. *Calamocladus* 6·30 p. c. Calamite-cones 0·42 p. c. *Myrophyllites* 9·54 p. c. *Pinnularia* 0·07 p. c.
Sphenophyllales. 361 Plants =6·51 p. c.	—	*Sphenophyllum*.........262	*Sphenophyllum*......... 36	*Sphenophyllum*......... 63	*Sphenophyllum*.........361
Lycopodiales. 2151 Plants =38·79 p. c.	*Lepidodendron* 55·73 p. c. *Sigillaria* 8·68 p. c. *Lepidostrobus* 29·34 p. c. *Bothrodendron* 0·52 p. c. *Stigmaria* 5·73 p. c.	*Lepidodendron* 77·88 p. c. *Sigillaria* 3·96 p. c. *Lepidostrobus* 17·49 p. c. *Lepidophloios* 0·33 p. c. *Stigmaria* 0·34 p. c.	*Lepidodendron* 37·59 p. c. *Sigillaria* 1·16 p. c. *Lepidostrobus* 58·78 p. c. *Bothrodendron* 0·29 p. c. *Stigmaria* 2·18 p. c.	*Lepidodendron* 55·74 p. c. *Sigillaria* 9·78 p. c. *Lepidostrobus* 10·98 p. c. *Bothrodendron* 2·22 p. c. *Stigmaria* 21·28 p. c.	*Lepidodendron* 53·05 p. c. *Sigillaria* 5·90 p. c. *Lepidophloios* 0·05 p. c. *Bothrodendron* 0·83 p. c. *Lepidostrobus* 32·12 p. c. *Stigmaria* 8·05 p. c.
Filicales and Pteridosperms. 551 Plants. =9·93 p. c.	*Neuropteris* 29·73 p. c. *Mariopteris* 2·77 p. c. *Sphenopteris* 5·41 p. c. *Pecopteris* 2·77 p. c. Rachis of Fern 56·56 p. c. *Cyclopteris* 2·76 p. c.	*Neuropteris* 3·86 p. c. *Mariopteris* 20·24 p. c. *Sphenopteris* 1·45 p. c. *Pecopteris* 1·45 p. c. Rachis of Fern 73·00 p. c. —	*Neuropteris* 2·83 p. c. *Mariopteris* 10·37 p. c. *Sphenopteris* 0·94 p. c. *Pecopteris* 1·88 p. c. Rachis of Fern 83·98 p. c. —	*Neuropteris* 0·49 p. c. *Mariopteris* 15·93 p. c. *Sphenopteris* 5·47 p. c. *Pecopteris* 2·47 p. c. Rachis of Fern 75·64 p. c. —	*Neuropteris* 4·17 p. c. *Mariopteris* 15·60 p. c. *Sphenopteris* 3·09 p. c. *Pecopteris* 2·00 p. c. Rachis of Fern 74·95 p. c. *Cyclopteris* 0·19 p. c.
Cordaitales. 1038 Plants =18·73 p. c.	Cordaite-leaves 99·42 p. c. — — Seeds? ... 0·58 p. c.	Cordaite-leaves 95·00 p. c. — *Samaropsis* 0·71 p. c. Seeds? ... 4·29 p. c.	Cordaite-leaves 99·50 p. c. Pithcast: *Sternbergia* 0·50 p. c. — —	Cordaite-leaves 99·74 p. c. Pithcast: *Sternbergia* 0·26 p. c. — —	Cordaite-leaves 98·94 p. c. Pithcast: *Sternbergia* 0·19 p. c. *Samaropsis* 0·09 p. c. Seeds? ... 0·78 p. c.

Fig. 8.



Ecology of Plants.
Pentre Seam.
Gilfach Goch.
Chart shewing distribution of Plants found in 209 blocks of Shale.
Scale of Plants.
Calamites 28.11%
Asterophyllites 52.98%
Annularia 2.58%
Calamocladus 6.30%
Calamite Cones 0.42%
Myriophyllites 9.54%
Pinnularia 0.07%
Sphenophyllum.
Lepidodendron 53.05%
Sigillaria 5.60%
Lepidophloios 0.03%
Bothrodendron 0.83%
Lepidostrobus 32.12%
Stigmaria 8.05%
Neuropteris 4.14%
Mariopteris 15.60%
Sphenopteris 3.09%
Pecopteris 1.2%
Rachis of Fern 74.95%
Cyclopteris 0.19%
Cordaite Leaves 98.94%
Sternbergia (Artisia) 0.19%
Samaropsis 0.09%
Seeds 0.78%
Equisetales.
Sphenophyllales.
Lycopodiales.
Filicales & Pteridosperms.
Cordaitales.
Sphenophyllales.
Lycopodiales
Filicales & Pteridosperms
Cordaitales.
Percentage Scale.
Percentage Scale of Classes.

Table VIII.

Different Classes.	A^1 to Z^1.	A^2 to Z^2.	A^3 to Z^3.	A^4 to Z^4.	A^1 to Z^4.
	Abergorky Seam, Blaenclydach Colliery, Clydach Vale.				
	Blocks of Shale = 84 Total Plants =915	Blocks of Shale = 69 Total Plants =971	Blocks of Shale = 46 Total Plants =1039	Blocks of Shale = 52 Total Plants =1149	Blocks of Shale examined = 251 Total Plants recorded =4074
Equisetales. 3434 Plants =84·29 p. c.	*Calamites* 4·79 p. c. *Asterophyllites* 82·29 p. c. *Annularia* 0·29 p. c. — — *Myrophyllites* 12·63 p. c.	*Calamites* 2·22 p. c. *Asterophyllites* 67·53 p. c. — Calamite-cones 0·12 p. c. — *Myrophyllites* 30·13 p. c.	*Calamites* 1·92 p. c. *Asterophyllites* 50·69 p. c. — — *Calamocladus* 0·10 p. c. *Myrophyllites* 47·29 p. c.	*Calamites* 1·80 p. c. *Asterophyllites* 58·41 p. c. *Annularia* 0·10 p. c. Calamite-cones 0·10 p. c. — *Myrophyllites* 39·59 p. c.	*Calamites* 2·53 p. c. *Asterophyllites* 63·25 p. c. *Annularia* 0·09 p. c. Calamite-cones 0·06 p. c. *Calamocladus* 0·03 p. c. *Myrophyllites* 34·04 p. c.
Sphenophyllales. 17 Plants =0·41 p. c.	*Sphenophyllum* 10	*Sphenophyllum* 4	—	*Sphenophyllum* 3	*Sphenophyllum* 17
Lycopodiales. 9 Plants =0·22 p. c.	*Lepidodendron* 50 p. c. *Sigillaria* — *Lepidostrobus* 50 p. c. *Stigmaria* —	*Lepidodendron* 25 p. c. — *Lepidostrobus* — *Stigmaria* 75 p. c.	*Lepidodendron* 33·3 p. c. *Sigillaria* 33·3 p. c. — *Stigmaria* 33·4 p. c.	— — — —	*Lepidodendron* 33·33 p. c. *Sigillaria* 11·11 p. c. *Lepidostrobus* 11·11 p. c. *Stigmaria* 44·45 p. c.
Filicales and Pteridosperms. 214 Plants =5·25 p. c.	*Neuropteris* 30·09 p. c. *Mariopteris* 4·85 p. c. *Eremopteris ?* 0·97 p. c. *Sphenopteris* 7·76 p. c. — Rachis of Fern 55·33 p. c. —	*Neuropteris* 43·34 p. c. *Mariopteris* 6·66 p. c. — *Sphenopteris* — — Rachis of Fern 50·00 p. c. —	*Neuropteris* 20 p. c. *Mariopteris* 13·33 p. c. — *Sphenopteris* 3·34 p. c. — Rachis of Fern 60 p. c. *Cyclopteris* 3·33 p. c.	*Neuropteris* 31·37 p. c. *Mariopteris* 29·41 p. c. *Eremopteris* 1·96 p. c. *Sphenopteris* 1·96 p. c. *Alethopteris* 7·84 p. c. Rachis of Fern 27·46 p. c. —	*Neuropteris* 30·75 p. c. *Mariopteris* 12·25 p. c. *Eremopteris* 0·93 p. c. *Sphenopteris* 4·67 p. c. *Alethopteris* 1·86 p. c. Rachis of Ferns or Fern-like Plants 49·06 p. c. *Cyclopteris* 0·48 p. c.
Cordaitales. 400 Plants. =9·83 p. c.	Cordaite-leaves 97·29 p. c. Pithcast : *Sternbergia* 0·90 p. c. — Seeds ? ... 1·81 p. c.	Calamite-leaves 99·18 p. c. — — Seeds ? ... 0·82 p. c.	Cordaite-leaves 94·20 p. c. — *Samaropsis* 1·46 p. c. Seeds ? ... 4·34 p. c.	Calamite-leaves 91·75 p. c. — *Samaropsis* 1·03 p. c. Seeds ? ... 7·22 p. c.	Calamite-leaves 96 p. c. Pithcast : *Sternbergia* 0·25 p. c. *Samaropsis* 0·50 p. c. Seeds ? ... 3·25 p. c.

Fig. 9.

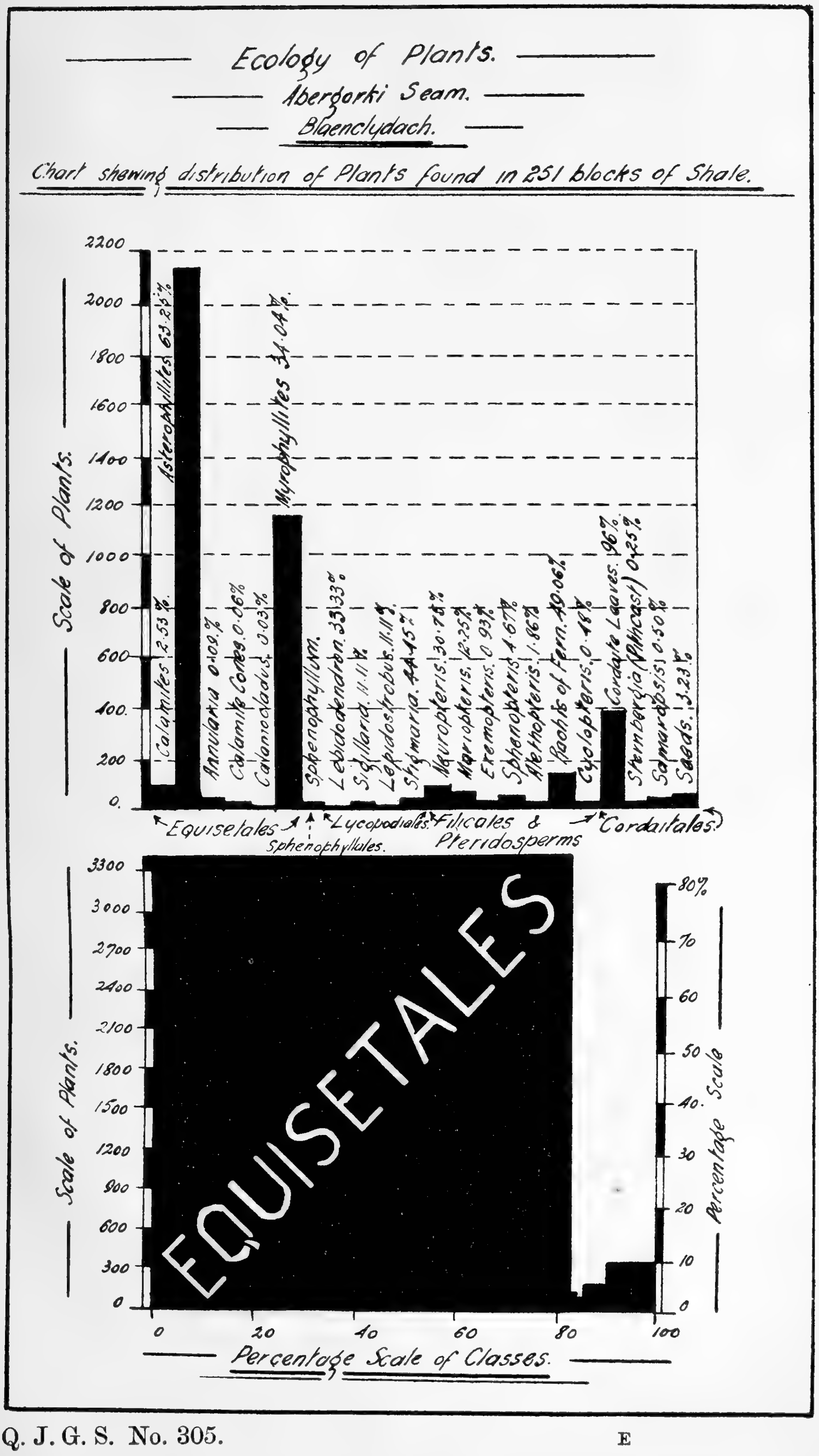

Ecology of Plants.
Abergorki Seam.
Blaenclydach.
Chart showing distribution of Plants found in 251 blocks of Shale.
Scale of Plants.
Calamites. 2.53%
Asterophyllites 63.29%
Annularia 0.09%
Calamite Cones 0.06%
Calamocladus. 0.03%
Myriophyllites 34.04%
Sphenophyllum.
Lepidodendron 33.33%
Sigillaria. 11.11%
Lepidostrobus. 11.11%
Equisetales
Sphenophyllales.
Lycopodiales.
Filicales & Pteridosperms
Cordaitales.
Cordaite Leaves. 96%
Percentage Scale
EQUISETALES
Percentage Scale of Classes.

Table IX.

Different Classes.	A^1 to Z^1.	A^2 to Z^2.	A^3 to Z^3.	A^4 to Z^4.	A^1 to Z^4.
	No. 3 Rhondda Seam, Glamorgan Colliery, Gilfach Goch.				
	Blocks of Shale = 35 Total Plants =1318	Blocks of Shale = 32 Total Plants =1459	Blocks of Shale = 38 Total Plants =1485	Blocks of Shale = 30 Total Plants =1530	Blocks of Shale examined = 135 Total Plants recorded =5792
Equisetales. 2258 Plants =39 p. c.	*Calamites* 18 p. c. *Asterophyllites* 16·66 p. c. *Calamocladus* 8·45 p. c. *Annularia* 8·71 p. c. Calamite-phragma 0·25 p. c. Calamite-leaves 1·8 p. c. Calamite-cones 0·51 p. c. *Palæostachya* 0·25 p. c. *Myrophyllites* 44·35 p. c. *Pinnularia* 1·02 p. c.	*Calamites* 26·88 p. c. *Asterophyllites* 34·62 p. c. *Calamocladus* 1·93 p. c. *Annularia* 10·54 p. c. Calamite-phragma 1·05 p. c. Calamite-leaves —— Calamite-cones —— *Palæostachya* 2·98 p. c. *Myrophyllites* 21·26 p. c. *Pinnularia* 0·74 p. c.	*Calamites* 14·25 p. c. *Asterophyllites* 37·72 p. c. *Calamocladus* 8·07 p. c. *Annularia* 5·53 p. c. Calamite-phragma 0·35 p. c. Calamite-leaves 0·63 p. c. Calamite-cones 0·35 p. c. —— *Myrophyllites* 23·60 p. c. *Pinnularia* 9·50 p. c.	*Calamites* 17·94 p. c. *Asterophyllites* 42·94 p. c. *Calamocladus* 7·73 p. c. *Annularia* 8·23 p. c. Calamite-phragma 0·29 p. c. —— Calamite-cones 0·29 p. c. *Palæostachya* 0·89 p. c. *Myrophyllites* 20·94 p. c. *Pinnularia* 0·75 p. c.	*Calamites* 19·17 p. c. *Asterophyllites* 34·81 p. c. *Calamocladus* 6·46 p. c. *Annularia* 8·14 p. c. Calamite-phragma 0·48 p. c. Calamite-leaves 0·48 p. c. Calamite-cones 0·26 p. c. *Palæostachya* 1·06 p. c. *Myrophyllites* 25·91 p. c. *Pinnularia* 3·23 p. c.
Sphenophyllales. 61 Plants =1·05 p. c.	*Sphenophyllum*............1	*Sphenophyllum* ——	*Sphenophyllum* 34	*Sphenophyllum* 26	*Sphenophyllum* 61
Lycopodiales. 14 Plants =0·24 p. c.	*Lepidodendron* 20 p. c. *Sigillaria* 60 p. c. *Stigmaria* 20 p. c.	—— *Sigillaria* 100 p. c. ——	*Lepidodendron* 100 p. c. —— ——	—— *Sigillaria* 100 p. c. ——	*Lepidodendron* 28·57 p. c. *Sigillaria* 64·28 p. c. *Stigmaria* 7·15 p. c.
Filicales and Pteridosperms. 2342 Plants =40·43 p. c.	*Neuropteris* 20·26 p. c. *Mariopteris* 1·65 p. c. *Sphenopteris* 30·75 p. c. *Crossotheca* 0·35 p. c. *Pecopteris* 1·11 p. c. *Eremopteris(?)* 0·35 p. c. Rachis of Fern 45·53 p. c. *Cyclopteris* ——	*Neuropteris* 44·94 p. c. *Mariopteris* 1·29 p. c. *Sphenopteris* 28·27 p. c. *Crossotheca* 0·16 p. c. *Pecopteris* 2·28 p. c. *Eremopteris(?)* 1·79 p. c. Rachis of Fern 21·11 p. c. *Cyclopteris* 0·16 p. c.	*Neuropteris* 26·62 p. c. *Mariopteris* 4·24 p. c. *Sphenopteris* 23·77 p. c. *Crossotheca* —— *Pecopteris* 0·15 p. c. *Eremopteris(?)* 4·00 p. c. Rachis of Fern 40·00 p. c. *Cyclopteris* 1·22 p. c.	*Neuropteris* 36 26 p. c. *Mariopteris* 2·54 p. c. *Sphenopteris* 29·55 p. c. —— *Pecopteris* 1·45 p. c. *Eremopteris* 0·56 p. c. Rachis of Fern 29·29 p. c. *Cyclopteris* 0·35 p. c.	*Neuropteris* 32·36 p. c. *Mariopteris* 2·47 p. c. *Sphenopteris* 27·96 p. c. *Crossotheca* 0·13 p. c. *Pecopteris* 1·24 p. c. *Eremopteris* 1·74 p. c. Rachis of Ferns or Fern-like Plants 33·63 p. c. *Cyclopteris* 0·47 p. c.
Cordaitales. 1117 Plants =19·28 p. c.	Cordaite-leaves 96·87 p. c. Pithcast: *Sternbergia* 0·26 p. c. —— Seeds? ... 2·87 p. c.	Cordaite-leaves 98·8 p. c. Pithcast: *Sternbergia* 0·80 p. c. —— Seeds? ... 0·40 p. c.	Cordaite-leaves 97·32 p. c. Pithcast: *Sternbergia* 1·07 p. c. —— Seeds? ... 1·61 p. c.	Cordaite-leaves 95·63 p. c. —— *Samaropsis* 3·63 p. c. Seeds? ... 0·74 p. c.	Cordaite-leaves 97·14 p. c. Pithcast: *Sternbergia* 0·44 p. c. *Samaropsis* 0·88 p. c. Seeds? ... 1·54 p. c.

Fig. 10.

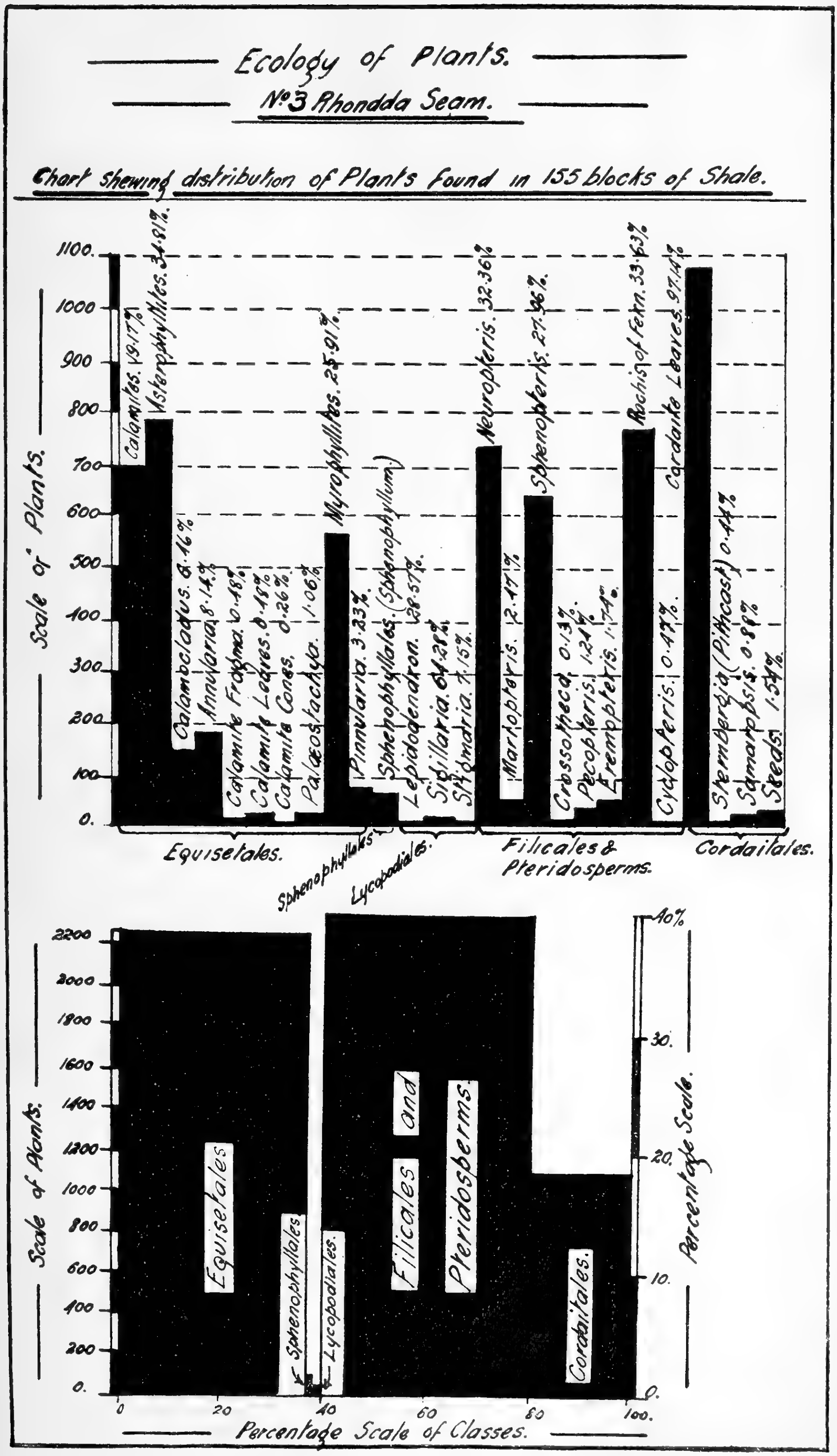
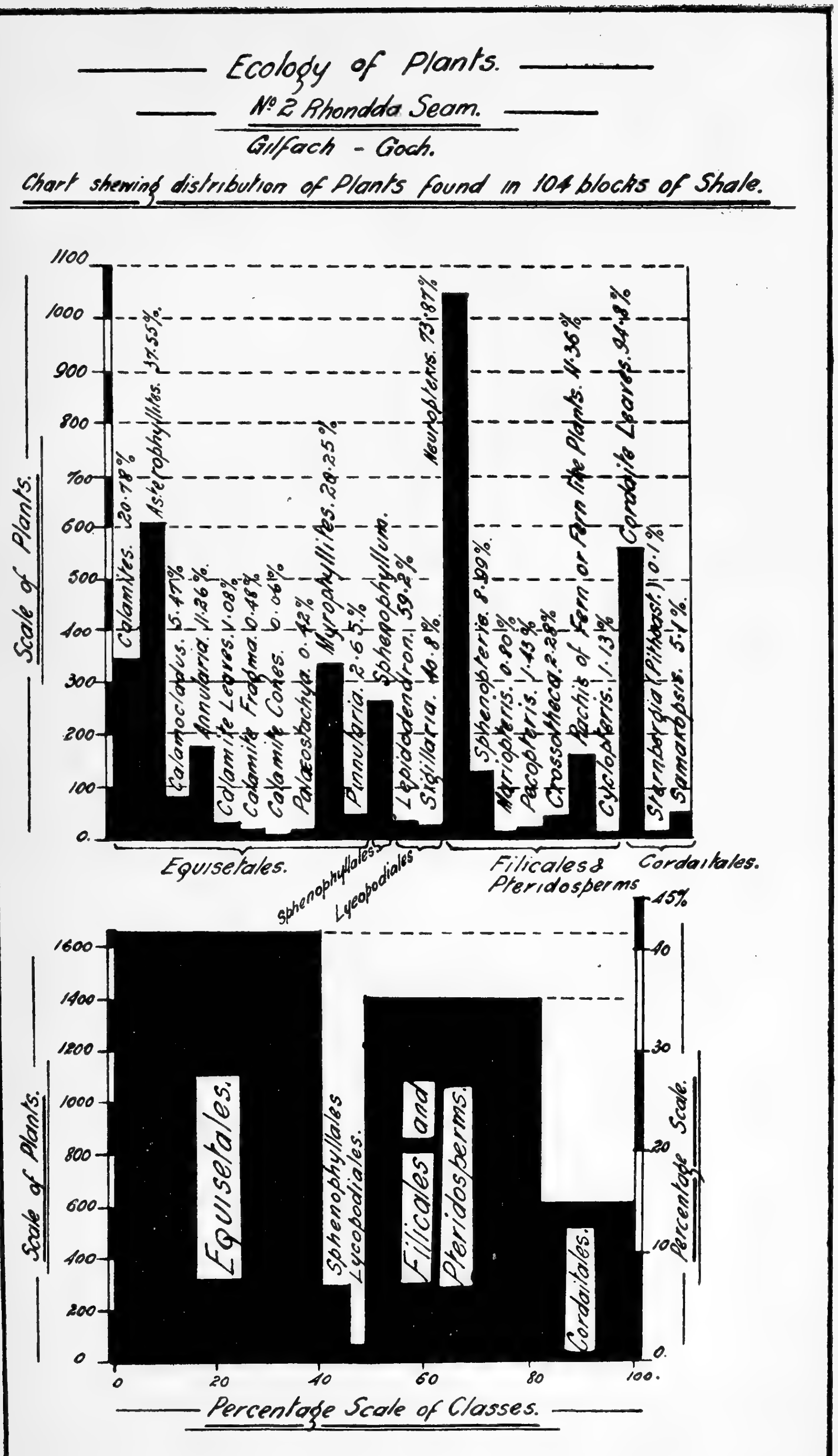

Ecology of Plants.
No3 Rhondda Seam.
Chart shewing distribution of Plants found in 155 blocks of Shale.
Scale of Plants.
Calamites. 19.17%
Asterophyllites.
Calamocladus. 8.16%
Annularia 8.14%
Calamite Fronds 0.48%
Calamite Leaves. 0.48%
Calamite Cones. 0.26%
Palæostachya. 1.06%
Myriophyllites. 25.91%
Pinnularia. 3.23%
Sphenophyllales. (Sphenophyllum)
Lepidodendron. 28.57%
Sigillaria. 64.28%
Stigmaria. 7.15%
Neuropteris. 32.36%
Mariopteris. 2.47%
Sphenopteris. 27.96%
Crossotheca 0.13%
Pecopteris. 1.21%
Eremopteris. 1.74%
Rachis of Fern. 33.63%
Cyclopteris. 0.47%
Cordaite Leaves. 97.14%
Sternbergia (Pithcast) 0.44%
Samaropsis. 0.86%
Seeds. 1.54%
Equisetales.
Sphenophyllales.
Lycopodiales.
Filicales & Pteridosperms.
Cordaitales.
Scale of Plants.
Equisetales
Sphenophyllales
Lycopodiales.
Filicales and Pteridosperms.
Cordaitales.
Percentage Scale.
Percentage Scale of Classes.

Table X.

Different Classes.	A¹ to Z¹.	A² to Z².	A³ to Z³.	A⁴ to Z⁴.	A¹ to Z⁴.
	No. 2 Rhondda Seam, Dinas Main Colliery, Gilfach Goch.				
	Blocks of Shale = 26 Total Plants =843	Blocks of Shale = 26 Total Plants =1120	Blocks of Shale = 26 Total Plants =890	Blocks of Shale = 26 Total Plants =1122	Blocks of Shale examined = 104 Total Plants recorded =3975
Equisetales. 1652 Plants =41·56 p. c.	*Calamites* 20·93 p. c.	*Calamites* 16·89 p. c.	*Calamites* 25·78 p. c.	*Calamites* 22·56 p. c.	*Calamites* 20·78 p. c.
	Asterophyllites 32·56 p. c.	*Asterophyllites* 36·85 p. c.	*Asterophyllites* 43·20 p. c.	*Asterophyllites* 37·68 p. c.	*Asterophyllites* 37·55 p. c.
	Calamocladus 6·74 p. c.	*Calamocladus* 7·29 p. c.	*Calamocladus* 4·88 p. c.	*Calamocladus* 2·66 p. c.	*Calamocladus* 5·47 p. c.
	Annularia 17·67 p. c.	*Annularia* 12·86 p. c.	*Annularia* 8·36 p. c.	*Annularia* 4·59 p. c.	*Annularia* 11·26 p. c.
	Calamite-leaves 3·07 p. c.	Calamite-leaves 0·76 p. c.	Calamite-leaves —	Calamite-leaves 0·24 p. c.	Calamite-leaves 1·08 p. c.
	Calamite-phragma 1·63 p. c.	—	—	Calamite-phragma 0·24 p. c.	Calamite-phragma 0·48 p. c.
	—	—	Calamite-cones 0·35 p. c.	—	Calamite-cones 0·06 p. c.
	Palæostachya 0·22 p. c.	*Palæostachya* 1·15 p. c.	—	—	*Palæostachya* 0·42 p. c.
	Myrophyllites 16·28 p. c.	*Myrophyllites* 20·35 p. c.	*Myrophyllites* 14·29 p. c.	*Myrophyllites* 28·74 p. c.	*Myrophyllites* 20·25 p. c.
	Pinnularia 0·90 p. c.	*Pinnularia* 3·85 p. c.	*Pinnularia* 3·14 p. c.	*Pinnularia* 3·29 p. c.	*Pinnularia* 2·65 p. c.
Sphenophyllales. 264 Plants =6·64 p. c.	*Sphenophyllum*......... 70	*Sphenophyllum*......... 96	*Sphenophyllum*......... 28	*Sphenophyllum*......... 70	*Sphenophyllum* 264
Lycopodiales. 49 Plants =1·23 p. c.	*Lepidodendron* 100 p. c.	*Lepidodendron* 62·07 p. c.	*Lepidodendron* —	*Lepidodendron* 66·6 p. c.	*Lepidodendron* 59·2 p. c.
	—	*Sigillaria* 37·93 p. c.	*Sigillaria* 100 p. c.	*Sigillaria* 33·4 p. c.	*Sigillaria* 40·8 p. c.
Filicales and Pteridosperms. 1427 Plants =35·89 p. c.	*Neuropteris* 7·66 p. c.	*Neuropteris* 66·8 p. c.	*Neuropteris* 75 p. c.	*Neuropteris* 75·86 p. c.	*Neuropteris* 73·87 p. c.
	Sphenopteris 17·48 p. c.	*Sphenopteris* 12·7 p. c.	*Sphenopteris* 2·55 p. c.	*Sphenopteris* 10·06 p. c.	*Sphenopteris* 8·99 p. c.
	Mariopteris 1·21 p. c.	—	*Mariopteris* 0·50 p. c.	*Mariopteris* 1·09 p. c.	*Mariopteris* 0·80 p. c.
	Pecopteris 0·61 p. c.	*Pecopteris* 1·65 p. c.	—	*Pecopteris* 2·75 p. c.	*Pecopteris* 1·43 p. c.
	Crossotheca 2·41 p. c.	*Crossotheca* 8·20 p. c.	*Crossotheca* 0·50 p. c.	*Crossotheca* 0·92 p. c.	*Crossotheca* 2·28 p. c.
	Rachis of Fern 5·42 p. c.	Rachis of Fern 7·37 p. c.	Rachis of Fern 18·93 p. c.	Rachis of Fern 8·23 p. c.	Rachis of Ferns or Fern-like plants 11·36 p. c.
	Cyclopteris 1·21 p. c.	*Cyclopteris* 3·28 p. c.	*Cyclopteris* 2·52 p. c.	*Cyclopteris* 1·09 p. c.	*Cyclopteris* 1·25 p. c.
Cordaitales. 583 Plants =14·68 p. c.	Cordaite-leaves 90 p. c.	Cordaite-leaves 94·8 p. c.	Cordaite-leaves 98·9 p. c.	Cordaite-leaves 100 p. c.	Cordaite-leaves 94·8 p. c.
	—	Pithcast : *Sternbergia* 0·40 p. c.	—	—	Pithcast : *Sternbergia* 0·1 p. c.
	Samaropsis 10 p. c.	*Samaropsis* 4·8 p. c.	*Samaropsis* 1·1 p. c.	—	*Samaropsis* 5·1 p. c.

Fig. 11.


Ecology of Plants.
No. 2 Rhondda Seam.
Gilfach - Goch.
Chart shewing distribution of Plants found in 104 blocks of Shale.
Scale of Plants.
Calamites. 20·78%
Asterophyllites. 37·55%
Calamocladus. 5·47%
Annularia. 11·26%
Calamite Leaves. 1·08%
Calamite Fragma. 0·48%
Calamite Cones. 0·06%
Palæostachya. 0·42%
Myriophyllites. 20·25%
Pinnularia. 2·65%
Sphenophyllum.
Lepidodendron. 59·2%
Sigillaria. 40·8%
Neuropteris. 73·87%
Sphenopteris. 8·99%
Mariopteris. 0·80%
Pecopteris. 1·43%
Crossotheca. 2·28%
Rachis of Fern or Fern like Plants. 11·36%
Cyclopteris. 1·13%
Cordaite Leaves. 94·8%
Sternbergia (Pithcast.) 0·1%
Samaropsis. 5·1%
Equisetales.
Sphenophyllales.
Lycopodiales
Filicales & Pteridosperms
Cordaitales.
Scale of Plants.
Equisetales.
Sphenophyllales Lycopodiales.
Filicales and Pteridosperms.
Cordaitales.
Percentage Scale.
Percentage Scale of Classes.

were devoid of plant-remains. The fossiliferous shales were obtained from 10 to 15 feet above the seam. The shales were of a gritty character throughout, and pale in colour.

Among the Equisetales, *Asterophyllites* dominated. *Sphenophyllum* was present, although very rare. Lycopodiales were also particularly scanty. Of the Filicales and Pteridosperms *Sphenopteris* was more numerous than the other genera. A notable feature in these shales was the great predominance of the rachis of ferns or fernlike plants, often with some of the petioles attached and stripped of their fronds and pinnules. Cordaitales were uncommon.

Of the remaining classes, Equisetales represent nearly four-fifths of the plants.

The Upper Yard Seam (Table III & fig. 4, pp. 38–39) lies 36 feet above the Middle Yard Seam at the Britannic Colliery, and is locally known as the Bute Seam. The shales for examination were obtained from beds about 8 to 14 feet above the seam, and were dark grey. The beds below this level failed to yield evidence of plant-remains; but a thin band of black shale was found to be impregnated with crushed shells of *Anthracomya phillipsi*: this band occurs 6 feet above the coal-seam. The area from which the shales were obtained lies nearly due west of the shaft, and at a distance of 1300 yards from it.

Of the Equisetales, *Calamites* dominates the other plants of the class. *Sphenophyllum* is again absent. Lycopodiales are beginning to assert themselves, as witnessed by a fair distribution of *Lepidodendron*. Of the Filicales and Pteridosperms, *Neuropteris* easily holds sway over the other genera, and, just as in the seam immediately below (the Middle Yard Seam), a great number of specimens of the rachis of ferns or fernlike plants are in evidence. Cordaite-leaves are also frequently found in these shales. The Filicales and Pteridosperms show a marked superiority in number over other classes.

The Nine-Foot Seam (Table IV & fig. 5, pp. 40–41) at the Trane Colliery occurs 150 feet above the Upper Yard Seam; but, owing to the limited development of this seam, the shale was obtained from a point 200 yards east of the shaft. The beds for 15 to 18 feet above the seam were nearly devoid of plant-remains; but a series of fossiliferous beds were struck about 18 to 24 feet above the seam. The shales examined were coarse and gritty, and in thin layers. The plant-remains were very much broken up. Of the Equisetales, *Asterophyllites* was most commonly met with, and represented two-thirds of the whole assemblage of plants belonging to this class; *Sphenophyllum* was again absent. Lycopodiales were rarely observed, and *Lepidodendron* was dominant. The Filicales and Pteridosperms were well represented by *Neuropteris*. Specimens of the rachis of ferns or fernlike plants were particularly rare, notwithstanding the fact

that *Neuropteris* was found in abundance. Cordaite-leaves were also frequently noticed. Equisetales represented two-fifths of the whole of the plants.

The Six-Foot Seam (Table V & fig. 6, pp. 42–43).—This seam rests 45 feet above the Nine-Foot Seam at the Trane Colliery. The shales overlying the seam were of a coarse grain, similar to those of the Nine-Foot Seam below. The beds here were somewhat more massive. No plant-remains were found in the shales immediately above the seam. At a position from 6 to 10 feet higher in the series fossiliferous beds were observed, and shales were taken from this point and from three other areas, each area being about 500 yards from the shaft. Work in this seam has but recently commenced, and consequently the area available for examination is very limited. The points from which the shales were obtained lie east, north, and south of the shaft. Of the Equisetales, *Asterophyllites* occurred in great profusion throughout the blocks of shale, the other genera belonging to this class being rare. A striking result of the examination is the absence of Sphenophyllales. Lycopodiales are also rare. The Filicales and Pteridosperms are strongly represented, and *Neuropteris* was found in great abundance, the other remaining genera being poorly represented. *Cyclopteris* (or *Aphlebia*) was rather common. Cordaite-leaves were also found in good numbers. The rachis of ferns or fernlike plants dominated the plants of other classes.

The Two-Foot Nine Seam (Table VI & fig. 7, pp. 44–45), at the Cambrian Collieries, Clydach Vale, is 135 feet above the Six-Foot Seam. The shales overlying the seam are massive, black, and of bituminous character.

Two bands of black shale, 8 and 22 feet respectively above the seam, were found rich in plant-remains. A marked change was noticed here in the flora. Beds of shale about 10, 24, and 30 feet respectively above the seam were observed to yield plant-remains, the intervening strata being barren of fossils. The shales were taken from two distinct areas about 1000 yards from the shaft (No. 4 Pit), in directions due west and north-west respectively from the shaft. Equisetales were scanty, and only two genera were found belonging to this class. Sphenophyllales are again absent. Lycopodiales occurred in great abundance for the first time at the different horizons. *Lepidodendron* occurred throughout the shales, and easily dominated the other genera of this class, although *Sigillaria* was not by any means rare. Specimens of the rachis of ferns or fernlike plants were practically absent from the shales, but Cordaite-leaves were fairly well represented. The Lycopodiales represent more than three-fifths of the whole assemblage of plants recorded.

The Pentre Seam (Table VII & fig. 8, pp. 46–47), Trane Colliery, Gilfach Goch, occurs 495 feet above the Four-Foot Seam,

the former seam lying 600 feet above the Six-Foot Seam. Argillaceous shales are found above that seam for a distance of about 10 feet, and immediately above these the shale is siliceous. The shales were obtained from north, south, east, and west of the shaft. Both kinds of shales were obtained from each area at a point about 350 yards from the shaft. Of the Equisetales, *Asterophyllites* proved to be more numerous than *Calamites*, although the latter were sufficiently numerous. Sphenophyllales are fairly well represented here for the first time, as it will be noticed that the underlying horizons yield no evidence of their presence, excepting the Middle Yard Seam, and even there they were very rarely found. Lycopodiales are still abundant, *Lepidodendron* alone representing a fifth of the whole of the plants recorded. *Bothrodendron* was found only in this seam. Filicales and Pteridosperms show *Mariopteris* dominating the other genera of ferns or fernlike plants for the first time. Specimens of the rachis of ferns are also very much in evidence. Cordaite-leaves, too, are frequently found.

Lycopodiales for the second time show their predominance over the other classes of plants.

The Abergorky Seam (Table VIII & fig. 9, pp. 48-49).—This seam lies at a depth of 360 feet at the Blaenclydach Colliery, Clydach Vale. The shales were obtained from an extensive area, in directions south-east and west respectively from the shaft. The shales examined were obtained from beds between 5 and 12 feet above the coal-seam; they were uniformly coarse-grained and siliceous. Of the Equisetales, specimens of *Asterophyllites* were very common throughout, numbering slightly more than half the whole of the plant-remains from the other classes. Sphenophyllales are again very rare, and Lycopodiales all but absent. The ferns or fernlike plants are somewhat scanty, *Neuropteris* dominating the other genera. Cordaite-leaves were found fairly often. The Equisetales are very numerous, and exceed in number all the other classes of plants put together.

The No. 3 Rhondda Seam (Table IX & fig. 10, pp. 50–51).—The shales overlying this seam are invariably light in colour and of fine texture. Blocks of shales were obtained near the shaft, and also from a point 3000 yards distant. The direction from which the shales were obtained lies north-east of the Glamorgan Colliery, Gilfach Goch; the seam is met with 299 feet down the shaft, and overlies the Abergorky Seam, with a thickness of strata of 59 feet between the two seams. The shales for examination were obtained from 3 to 12 feet above the coal-seam, and were very fossiliferous.

Of the Equisetales *Asterophyllites* occurred in abundance, and were more numerous than any of the other plants related to this class. Sphenophyllales were met with rather frequently. Lycopodiales were very rare. The ferns or fernlike plants were well

represented, *Neuropteris* and *Sphenopteris* being common, the former genus slightly dominating the latter. Cordaite-leaves also were well maintained in their distribution, and seeds belonging to *Cordaites* were common. Of the several classes of plants, the rachis of ferns or fernlike plants slightly predominated over the Equisetales.

The No. 2 Rhondda Seam (Table X & fig. 11, pp. 52–53) crops out a few feet above the brook-level at Gilfach Goch. Shales were got from the mouth of the main roadway and inbye, 3200 yards apart: the direction from the mouth of the level of the points where the shales were observed was west and north-west. They were obtained from 3 to 10 feet above the coal-seam. The shales are dark grey and of a very fine grain, with abundant plant-remains. Of the Equisetales, *Asterophyllites* is again found dominating the other genera of plants. Sphenophyllales are not by any means rare. Lycopodiales are still poorly represented. Of the ferns and fernlike plants *Neuropteris* is the predominant genus. Cordaite-leaves are now somewhat rarer than at the other horizons. The Equisetales are once again superior in number to the plants of the other classes.

III. The Proportional Distribution of Individual Genera in the Floral Assemblages of the Various Horizons.

Calamites.—This genus is found frequently in the Five-Foot Seam, and represents nearly a sixth of the different genera of plants. It increases rapidly in number in the Middle Yard Seam, where it is found to reach its maximum at the different horizons. The Upper Yard Seam shows a decrease in numbers, with a gradual diminution in the Nine-Foot Seam, rapidly falling lower still in the Six-Foot Seam; but *Calamites* gradually increases in number in the Two-Foot Nine and Pentre Seams respectively.

In the Abergorky Seam, *Calamites* reaches its lowest ebb, but gradually increases in number in the No. 3 and No. 2 Rhondda Seams.

Asterophyllites.—The genus is somewhat scanty in the Five-Foot Seam, occurs in great profusion in the Middle Yard Seam, but diminishes rapidly in the Upper Yard Seam. The distribution is found to be fairly wide in the Nine-Foot and Six-Foot Seams, but the genus almost disappears in the Two-Foot Nine Seam, which is the lowest point of its distribution. The Pentre Seam shows an increase in the number of plants, and the maximum is reached in the Abergorky Seam. After this *Asterophyllites* again becomes scantier in the No. 3 and No. 2 Rhondda Seams.

Calamocladus.—(The species now known as *Asterophyllites charæformis* was formerly known as *Calamocladus charæformis.*) The genus is very weak in the Five-Foot and the Middle Yard Seams, then it entirely disappears in the Upper Yard, Nine-Foot,

Six-Foot, and Two-Foot Nine Seams. It again appears very scantily in the Pentre Seam, and is almost absent in the Abergorky Seam; but it is more evident in the No. 3 and No. 2 Rhondda Seams.

Annularia.—Is feeble in the Five-Foot Seam, disappears in the Middle Yard Seam, and is very rare in the Upper Yard and Nine-Foot Seams. There were no specimens found in the Six-Foot and Two-Foot Nine Seams; but a few were found in the Pentre and Abergorky Seams, and they are numerous in the No. 3 and No. 2 Rhondda Seams.

Calamite Stem-Leaves.—The narrow linear leaves of *Calamites* were only met with in the Five-Foot Seam and the two uppermost horizons: namely, No. 3 and No. 2 Rhondda Seams.

Calamite-Phragma.—The phragma of *Calamites* did not occur in the Five-Foot Seam, very rarely in the Middle Yard Seam, was absent in the Upper Yard Seam, rare in the Nine-Foot and Six-Foot Seams, disappearing in the Two-Foot Nine, Pentre, and Abergorky Seams, and feebly evident in the No. 3 and No. 2 Rhondda Seams.

Calamite-Cones.—These were observed in the three lowest horizons and in the four highest horizons; but the Nine-Foot, Six-Foot, and Two-Foot Nine Seams yielded no evidence.

Palæostachya.—Absent in the Five-Foot and Middle Yard Seams, rare in the Upper Yard Seam, no evidence in the five succeeding horizons in ascending order, rather frequent in the No. 3, and again becoming rare in the No. 2 Rhondda Seam.

Myrophyllites.—Weak in the Five-Foot Seam, becoming more abundant in the Middle Yard Seam, with a slight decrease in the Upper Yard Seam and Nine-Foot Seam, very rare in the Six-Foot Seam, absent in the Two-Foot Nine Seam, feeble in the Pentre Seam, abundant in the Abergorky Seam, and becoming less common in the No. 3 and No. 2 Rhondda Seams.

Pinnularia.—Entirely absent at the six lower horizons, weak in the Pentre Seam, yielding no evidence in the Abergorky Seam, frequent in the No. 3 Rhondda Seam, and becoming reduced in number in the No. 2 Rhondda Seam.

Sphenophyllum.—Absent in the Five-Foot Seam, rare in the Middle Yard Seam, no evidence in the five succeeding horizons from the Middle Yard Seam to the Pentre Seam, but well represented in this seam, becoming rare again in the Abergorky Seam and increasing in the No. 3 Rhondda Seam; very common in the No. 2 Rhondda Seam.

Lepidodendron.—Very rare in the Five-Foot Seam and Middle Yard Seam, increasing considerably in the Upper Yard Seam, becoming continuously scantier in the Nine-Foot and Six-Foot

Seams. In the Two-Foot Nine Seam, *Lepidodendron* suddenly becomes the dominating genus, and continues in this state of superiority, but in a less degree, in the Pentre Seam. It afterwards disappears in the Abergorky Seam, and in the No. 3 and No. 2 Rhondda Seams.

SIGILLARIA.—Similarly to *Lepidodendron* this genus passes upwards through the different horizons, the two genera increasing and diminishing in number simultaneously: the only difference noticeable being the numerical preponderance of *Lepidodendron* over *Sigillaria* in each case.

BOTHRODENDRON.—Rare, found only at one horizon: that is, the Pentre Seam.

LEPIDOPHLOIOS.—Very rare, found in the Pentre Seam only.

LEPIDOSTROBUS.—Absent in the Five-Foot and Middle Yard Seams, rare in the Upper Yard and Nine-Foot Seams, not found in the Six-Foot Seam, common in the Two-Foot Nine and Pentre Seams, very rare in the Abergorky and No. 3 Rhondda Seams, and absent in the No. 2 Rhondda Seam.

STIGMARIA.—Absent in the Five-Foot and Middle Yard Seams, rare in the Upper Yard and Nine-Foot Seams, absent in the Six-Foot Seam, common in the Two-Foot Nine and Pentre Seams, very rare in the Abergorky and No. 3 Rhondda Seams, and absent in the No. 2 Rhondda Seam.

NEUROPTERIS.—Fair distribution in the Five-Foot Seam, feeble in the Middle Yard Seam, abundant in the Upper Yard and Nine-Foot Seams, still increasing in number and reaching the maximum in the Six-Foot Seam, nearly absent in the Two-Foot Nine, Pentre, and Abergorky Seams, regaining its vitality with a strong representation in the No. 3 and No. 2 Rhondda Seams.

SPHENOPTERIS.—Persistent, but not so numerous as *Neuropteris*, only once dominating the latter genus (that is, in the Middle Yard Seam), common in the Middle Yard Seam; then it gradually diminishes at the other horizons until the Two-Foot Nine Seam is reached, where it is absent. *Sphenopteris* appears scantily in the Pentre and Abergorky Seams, very prominently in the No. 3 Rhondda Seam, but decreases markedly in the No. 2 Rhondda Seam.

MARIOPTERIS.—This genus, like *Sphenopteris*, is rather persistent, although few specimens were found. It appears scantily in the Five-Foot Seam, is absent in the Middle Yard Seam, very rare in the Upper Yard Seam, absent in the Nine-Foot Seam, and very rare in the Six-Foot Seam and the Two-Foot Nine Seam. The Pentre Seam shows it at its maximum of distribution, and here it dominates the other genera of its class. It is rather rare

in the Abergorky Seam, increases in number in the No. 3 Rhondda Seam, but is rarely found in the No. 2 Rhondda Seam.

PECOPTERIS.—Absent at the three lowest horizons, scanty in the Nine-Foot and Six-Foot Seams, absent in the Two-Foot Nine Seam, extremely rare in the Pentre Seam, absent in the Abergorky Seam, and very rare in the No. 3 and No. 2 Rhondda Seams.

ALETHOPTERIS.—Particularly abundant in the Five-Foot Seam, extremely rare in the Middle Yard Seam, absent in the Upper Yard Seam, very rare in the Nine-Foot and Six-Foot Seams, absent in the Two-Foot Nine and Pentre Seams, very scanty in the Abergorky Seam, disappearing in the No. 3 and No. 2 Rhondda Seams.

CROSSOTHECA.—This genus was not observed at any horizon below the No. 3 Rhondda Seam, and at this point was extremely rare. The specimens found in the No. 2 Rhondda Seam were ten times more numerous than those found in the No. 3 Rhondda Seam.

EREMOPTERIS (?).—Absent at the seven lowest horizons, very rare in the Abergorky Seam, rather common in the No. 3 Rhondda Seam, and absent in the No. 2 Rhondda Seam.

RACHIS OF FERNS OR FERNLIKE PLANTS.—Scanty in the Five-Foot Seam, common in the Middle Yard and Upper Yard Seams, very uncommon at the succeeding horizons, more frequent in the Pentre Seam, rarer in the Abergorky Seam, common again in the No. 3 Rhondda Seam, but decreasing in number in the No. 2 Rhondda Seam.

CYCLOPTERIS (Scale-leaves).—Absent at two horizons, namely, the Middle Yard and Two-Foot Nine Seams, always rare at the other horizons, with the exception of the Six-Foot Seam, where it is common.

SEEDS (possibly of a Pteridospermous nature).—These were only found at the three lowest horizons.

CORDAITE-LEAVES.—Very prevalent in the Five-Foot Seam, where they easily dominate the other genera of plants. They are very feeble in the Middle Yard Seam, are well distributed in the Upper Yard and Nine-Foot Seams, with a slight decrease in the Six-Foot Seam, prominent again in the Two-Foot Nine Seam, reduced in number in the Pentre Seam (but even here they are abundant). They become considerably scantier in the Abergorky Seam, commoner in the No. 3 Rhondda Seam, and diminish in number in the No. 2 Rhondda Seam.

STERNBERGIA (pithcast).—Very rare throughout; absent in the Middle Yard and Six-Foot Seams.

SAMAROPSIS.—Absent in the Five-Foot and Middle Yard Seams, extremely rare in the Upper Yard and Nine-Foot Seams, absent

in the Six-Foot and Two-Foot Nine Seams, extremely rare in the Pentre and Abergorky Seams, more numerous in the No. 3 Rhondda Seam, and still more frequent in the No. 2 Rhondda Seam.

SEEDS (probably belonging to *Cordaites*).—Not present at the three lowest horizons and the No. 2 Rhondda Seam. Very weakly represented at the remaining six horizons: namely, from the Nine-Foot to the No. 3 Rhondda Seam.

The Different Classes of Plants as a Whole.

EQUISETALES.—Rather abundant in the Five-Foot Seam and dominating the other classes in the Middle Yard Seam. In the Upper Yard Seam the distribution is similar to that of the Five-Foot Seam. They are again dominant in the Nine-Foot Seam, appearing still numerous in the Six-Foot Seam, scanty in the Two-Foot Nine Seam, considerably stronger in the Pentre Seam, and for the third time they easily dominate the other classes in the Abergorky Seam, and maintain a very strong position in the No. 3 Rhondda Seam. In the No. 2 Rhondda Seam, they predominate over the other plants for the fourth time by a narrow margin.

SPHENOPHYLLALES. See *Sphenophyllum*.

LYCOPODIALES.—Particularly scanty in the Five-Foot and Middle Yard Seams, increasing in the Upper Yard Seam, gradually weakening in the Nine-Foot and Six-Foot Seams, dominant at two horizons in succession (namely, the Two-Foot Nine and Pentre Seams), and disappearing in the Abergorky, No. 3 Rhondda, and No. 2 Rhondda Seams.

FERNS and FERNLIKE PLANTS.—Wide distribution in the Five-Foot and Middle Yard Seams, dominant in the Upper Yard Seam, with a good representation in the Nine-Foot Seam. They become dominant in the Six-Foot Seam. These plants suddenly disappear in the Two-Foot Nine, Pentre, and Abergorky Seams, but are conspicuous and become dominant for the third time in the No. 3 Rhondda Seam, maintaining a strong position in the No. 2 Rhondda Seam.

CORDAITALES.—Dominant in the Five-Foot Seam, and well represented throughout the nine succeeding horizons, with the exception of one weak point of distribution found in the Middle Yard Seam.

The following list of species embodies (*a*), those species which are common to the Westphalian and Staffordian Series; (*b*), those belonging to the Westphalian only; and (*c*), those belonging to the Staffordian only. I am deeply indebted to Dr. R. Kidston, F.R.S., and to Dr. F. L. Kitchin, M.A., for the determination of the species of plants in my collection.

Westphalian and Staffordian Series.

Calamites carinatus.
Calamites cisti.
Calamites sachsei.
Calamites schutzeiformis, forma *waldenburgensis.*
Calamites semicircularis.
Calamites suckowii.
Calamites undulatus.
Asterophyllites charæformis.
Asterophyllites equisetiformis.
Asterophyllites longifolius.
Annularia radiata (vera).
Annularia radiata.
Annularia rimosa.
Annularia sphenophylloides.
Calamite-cones *(Calamostachys).*
Palæostachya sp.
Asterophyllites-equisetiformis cones *(Macrostachya).*
Myrophyllites gracilis (roots).
Pinnularia capillacea (roots).
Sphenophyllum cuneifolium.
Sphenophyllum majus.
Lepidodendron aculeatum.
Lepidodendron disetum.
Lepidodendron ophiurus.
Lepidodendron rimosum.
Lepidodendron simile.
Lepidophyllum sp.
Asolanus camptotænia.
Lepidostrobus sp.
Sigillaria tessellata.
Sigillaria (leaves).
Stigmaria ficoides.
Neuropteris callosa.
Neuropteris gigantea.
Neuropteris gigantea (falcata).
Neuropteris heterophylla.
Neuropteris obliqua.
Neuropteris rarinervis.
Neuropteris scheuchzeri.
Neuropteris tenuifolia.
Sphenopteris obtusiloba.
Pecopteris cf. *arborescens (?).*
Pecopteris (Asterotheca) miltoni.
Pecopteris volkmanyi.
Mariopteris acuta.
Mariopteris muricata.
Mariopteris muricata, forma *nervosa.*
Linopteris munsteri.
Crossotheca boulayi (with fructification).
Alethopteris lonchitica.
Cyclopteris (scale-leaf).
Trigonocarpus sp.
Eremopteris artemisiæfolia.
Seeds (probably pteridospermous ?).
Cordaites principalis.
Cordaites (leaves).
Artisia approximata.
Samaropsis meachemi.
Carpolithus sp.

Westphalian Series only.

Calamites gœpperti.
Calamites paleacus (foliage).
Calamites ramosus, var. *rugosus.*
Palæostachya elongata.
Sphenophyllum cuneifolium, forma *saxifragæfolium.*
Lepidodendron acutum.
Lepidodendron obovatum.
Bothrodendron punctatum.
Ulodendron (formerly known as *Sigillaria discophora*).
Lepidophloios acerosus.
Lepidophyllum lanceolatum.
Halonia regularis.
Lepidostrobus anthemis.
Lepidostrobus triangularis.
Sigillaria camptotænia.
Sigillaria elegans.
Sigillaria elongata.
Sigillaria lævigata.
Sigillaria mammillaris.
Sigillaria mammillaris (forma *tournaisii*).
Sigillaria rugosa.
Sigillaria scutellata.
Sigillaria (pithcast).
Stigmaria reticulata.
Stigmaria sp.
Neuropteris camptophylla.
Neuropteris flexuosa.
Neuropteris grangeri.
Neuropteris microphylla.
Zeilleria avoldensis.
Sphenopteris andreœna.
Sphenopteris hœningshausi.
Sphenopteris laurenti.
Sphenopteris nummularia.
Sphenopteris sauverii.
Sphenopteris sturi.
Pecopteris muricata (with fructification).
Crossotheca hœninghausi.
Alethopteris decurrens.
Alethopteris valida.
Aphlebia crispa.
Trigonocarpon parkinsoni.
Lagenospermum sp.
Cordaites (Dorycordaites) palmæformis.
Samaropsis pseudofluitans.
Cardiocarpus sp.
Seeds (probably belonging to *Cordaites ?*).
Dolerophyllum pseudopeltatum.

F A SINGLE GENUS OF PLATFORM OF THE TEN SEAMS,

NAMELY: FR

...lites.	Calamocladus.		A[ph]yllites.		Pinnularia.		Total Plants in a Class.	
...cent.		Per cent.		Per cent.		Per cent.		Per cent.
5·4	92	2·3	18	8·4	47	1·08	1652	41·6
3·4	146	2·5	18	10·6	73	1·2	2258	39
8·4	1	0·02		28·6	—	—	3434	84·3
0·1	91	1·1	3	2·5	1	0·01	1444	26
0·4	—	—	—	—	—	—	84	5·9
7·1	—	—	—	0·55	—	—	2854	40·7
6·6	—	—		3·3	—	—	2925	50·9
8·4	—	—		3·2	—	—	1452	31·3
6·3	.27	0·5	—	4·6	—	—	4292	72·1
8·8	13	0·7		2·2	—	—	566	30·9

...a.	Abergorky.		...dle Yard.		Five-Foot.	Total.
...r cent.		Per cent.		Per cent.		
1·05	17	0·4	3...	0·19	—	714

...ia.	Bothrodendron.		L...
...r cent.		Per cent.	
0·50	—	—	—
0·15	—	—	—
0·03	—	—	—
2·3	18	0·3	—
10·1	—	—	—
0·14	—	—	—
0·24	—	—	—
0·4	—	—	—
0·49	—	—	—
0·05	—	—	—

Aggregate
Total of Plants
= 45,953.

...ne specimen of
Ulodendron
...as found in the
Pentre Seam.]

TABLE XI.—THE DISTRIBUTION OF A SINGLE GENUS OF PLANTS AS RELATED TO THE DIFFERENT GENERA OF PLANTS ON EVERY PLATFORM OF THE TEN SEAMS, NAMELY: FROM THE FIVE-FOOT SEAM TO THE NO. 2 RHONDDA SEAM.

	Coal-Seams.	*Calamites.*		*Asterophyllites.*		*Calamocladus.*		*Annularia.*		Calamite-Leaves.		Calamite-Phragma.		Calamite-Cones.		*Palæostachya.*		*Myrophyllites.*		*Pinnularia.*		Total Plants in a Class.	
			Per cent.		Per cent.		Per cent.		Per cent.		Per cent.		Per cent.		Per cent.		Per cent.		Per cent.		Per cent.		Per cent.
EQUISETALES.	No. 2 Rhondda	345	8·7	612	15·4	92	2·3	186	4·6	18	0·5	8	0·2	1	0·02	7	0·19	336	8·4	47	1·08	1652	41·6
	No. 3 Rhondda	433	7·5	787	13·4	146	2·5	184	3·1	11	0·2	11	0·2	6	0·11	24	0·4	583	10·6	73	1·2	2258	39
	Abergorky	87	2·1	2172	48·4	1	0·02	3	0·07	—	—	—	—	2	0·04	—	—	1169	28·6	—	—	3434	84·3
	Pentre	406	7·3	765	10·1	91	1·1	37	0·71	—	—	—	—	6	0·10	—	—	138	2·5	1	0·01	1444	26
	Two-Foot Nine	78	5·5	6	0·4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	84	5·9
	Six-Foot	209	2·91	2600	37·1	—	—	—	—	—	—	2	0·03	—	—	—	—	43	0·55	—	—	2854	40·7
	Nine-Foot	620	10·8	2111	36·6	—	—	1	0·01	—	—	4	0·07	—	—	—	—	190	3·3	—	—	2925	50·9
	Upper Yard	863	18·5	389	8·4	—	—	2	0·04	—	—	—	—	40	0·86	4	0·08	154	3·2	—	—	1452	31·3
	Middle Yard	1816	30·5	2161	36·3	27	0·5	—	—	—	—	11	0·20	3	0·05	—	—	274	4·6	—	—	4292	72·1
	Five-Foot	310	16·9	161	8·8	13	0·7	6	0·30	28	1·5	—	—	8	0·5	—	—	40	2·2	—	—	566	30·9

	Coal-Seams.	No. 2 Rhondda.		No. 3 Rhondda.		Abergorky.		Pentre.		Two-Foot Nine.		Six-Foot.		Nine-Foot.		Upper Yard.		Middle Yard.		Five-Foot.	Total.
SPHENOPHYLLALES.	*Sphenophyllum*	264	Per cent. 6·7	61	Per cent. 1·05	17	Per cent. 0·4	361	Per cent. 6·5	—		—		—		—		11	Per cent. 0·19	—	714

	Coal-Seams.	*Lepidodendron.*		*Sigillaria.*		*Bothrodendron.*		*Lepidophloios.*		*Lepidostrobus.*		*Stigmaria.*		Total Plants in a Class.		Total Plants of different Classes.
			Per cent.		Per cent.		Per cent.		Per cent.		Per cent.		Per cent.		Per cent.	
LYCOPODIALES.	No. 2 Rhondda	29	0·73	20	0·50	—	—	—	—	—	—	—	—	49	1 23	3975
	No. 3 Rhondda	4	0·07	9	0·15	—	—	—	—	—	—	1	0·01	14	0·24	5792
	Abergorky	3	0·07	1	0·03	—	—	—	—	1	0·03	4	0·08	9	0·21	4074
	Pentre	1141	20·5	127	2·3	18	0·3	1	0·01	691	12·2	173	3·1	2151	38·6	5545
	Two-Foot Nine	647	46·1	142	10·1	—	—	—	—	18	1·2	128	9·2	935	66·6	1402
	Six-Foot	17	0·24	10	0·14	—	—	—	—	5	0·07	—	—	32	0·45	7004
	Nine-Foot	141	2·4	14	0·24	—	—	—	—	27	0·47	14	0·24	196	3·40	5745
	Upper Yard	434	9·3	19	0·4	—	—	—	—	34	0·80	4	0·10	491	10·6	4639
	Middle Yard	1	0·01	28	0·49	—	—	—	—	—	—	—	—	29	0·50	5946
	Five-Foot	3	0·16	1	0·05	—	—	—	—	—	—	—	—	4	0 21	1831

Aggregate Total of Plants = 45,953.

[One specimen of *Ulodendron* was found in the Pentre Seam.]

TALS OF THE PLANTS DETERM INVESTIGATION.

pteris.	Pecopteris.		Alethop	s.	Seeds.		Total Plants in a Class.	
Per cent.		Per cent.		P cent.		Per cent.		Per cent.
0·28	20	0·56	—	·75	—	—	1427	35·9
1·00	28	0·48	—	·2	—	—	2251	40·5
0·63	—	—	4	·03	—	—	214	5·2
1·5	11	0·2	—	·01	—	—	551	9·7
0·2	—	—	—	–	—	—	24	1 5
0·55	1	0·01	10	·80	—	—	3107	44·3
—	6	0·14	21	·04	—	—	1622	28·3
0·60	—	—	—	·06	4	0·08	1884	40·8
—	—	—	2	–	1	0·01	1536	26·5
1·6	—	—	183	·4	8	0·4	453	24·6

opsis.	Seeds.		Tota Plants a Cla	
Per cent.		Per cent.		P
0·73	—	—	583	
0·17	17	0·29	1117	
0·04	13	0·32	400	
0·01	8	0·14	1038	
—	2	0·13	359	
—	5	0·07	1011	
0·01	16	0·28	1002	
0·02	—	—	812	
—	—	—	78	
—	—	—	812	

TABLE XII.—PERCENTAGES AND TOTALS OF THE PLANTS DETERMINED IN THE TEN SEAMS WHICH FORMED THE OBJECT OF INVESTIGATION.

	Coal-Seams.	*Neuropteris.*		*Sphenopteris.*		*Mariopteris.*		*Pecopteris.*		*Alethopteris.*		*Crossotheca.*		*Eremopteris.*		Rachis of Ferns or Fernlike Plants.		*Cyclopteris.*		Seeds.		Total Plants in a Class.	
			Per cent.		Per cent.		Per cent.		Per cent.		Per cent.		Per cent.		Per cent.		Per cent.		Per cent.		Per cent.		Per cent.
FILICALES and PTERIDOSPERMS.	No. 2 Rhondda	1050	26·3	127	3·18	10	0·28	20	0·56	-	-	31	0·8	—	-	161	4·03	28	0·75	- -	—	1427	35·9
	No. 3 Rhondda	756	13·08	654	11·2	58	1·00	28	0·48	-	-	3	0·05	41	0·70	790	13·6	11	0·2			2251	40·5
	Abergorky	66	1·37	10	0·22	26	0·63	—		4	0·08	—	-	2	0·40	105	2·56	1	0·03		—	214	5·2
	Pentre	23	0·41	17	0·30	86	1·5	11	0·2	—	- -	-	—	—		413	7·4	1	0·01			551	9·7
	Two-Foot Nine	19	1·3	—	—	3	0·2	—	—	- -	- -	—	—	—		2	0·13	-	-	- -	- -	24	1·5
	Six-Foot	2964	42·3	4	0·06	43	0·55	1	0·01	10	0·14	—		-		28	0·4	57	0·80			3107	44·3
	Nine-Foot	1573	27·4	6	0·14	-	—	6	0·14	21	0·36	- -		-		11	0·19	5	0·04	—	-	1622	28·3
	Upper Yard	941	20·2	36	0·77	28	0·60	- -	- -	—	-	-	- -			872	18·8	3	0·06	4	0·08	1884	40·8
	Middle Yard	232	3·9	331	5·9	—	—			2	0·05	-	-	-		970	16·3		-	1	0·01	1536	26·5
	Five-Foot	114	6·2	40	2·2	31	1·6		- -	183	10	—	-	.	.	69	3·7	8	0·4	8	0·4	453	24·6

	Coal-Seams.	Cordaite Leaves.		(Pithcast) *Sternbergia.*		*Samaropsis.*		Seeds.		Total Plants in a Class.		Total Plants of different Classes.
			Per cent.		Per cent.		Per cent.		Per cent.		Per cent.	
CORDAITALES.	No. 2 Rhondda	553	13·92	1	0·03	29	0·73	—	—	583	14·68	3975
	No. 3 Rhondda	1085	18·8	5	0·08	10	0·17	17	0·29	1117	19·3	5792
	Abergorky	384	9·42	1	0·03	2	0·04	13	0·32	400	9·81	4074
	Pentre	1027	18·6	2	0·03	1	0·01	8	0·14	1038	18·7	5545
	Two-Foot Nine	335	23·8	2	0·13	—	—	2	0·13	359	24·06	1402
	Six-Foot	1006	14·2	—	—	—	—	5	0·07	1011	14·2	7004
	Nine-Foot	984	17·1	1	0·01	1	0·01	16	0·28	1002	17·44	5745
	Upper Yard	809	17·2	2	0·04	1	0·02	- -	—	812	17·26	4639
	Middle Yard	78	1·3	—	—	—	—	- -	—	78	1·3	5946
	Five-Foot	810	44·2	2	0·10	- -	—	—	—	812	44·3	1831

Aggregate Total of Plants = 45,953.

STAFFORDIAN SERIES only.

Calamites approximatus.
Calamites carinatus, forma *rugosus.*
Calamites schutzeiformis, forma *typicus.*
Equisetites rugosus.
Asterophyllites radiata (vera ?).
Annularia galioides.
Calamite stem-leaves.
Sphenophyllum emarginatum.
Sphenophyllum trichotomosum.
Lepidophloios laricinus.
Lepidophyllum aculeatum.
Lepidophyllum acuminatum.
Lepidocystis fraginiformis.
Sigillaria nudicaulis.
Sigillaria ovata.
Sigillaria schlotheimi.
Sigillaria walchi.
Sigillaria (with cone-scars) sp.
Sporangia of Sigillarian cone.
Neuropteris lonchitica.
Neuropteris obtusifolia.
Sphenopteris amœnia.
Sphenopteris artemisiæfolioides.
Sphenopteris (Renaultia) charæphylloides.
Sphenopteris coemansi.
Sphenopteris conwayi.
Sphenopteris latifolia.
Sphenopteris neuropteroides.
Sphenopteris obtusiloba (forma *convexiloba*).
Sphenopteris obtusifolia (?).
Sphenopteris renaulti (with fructification).
Sphenopteris rotundifolia.
Sphenopteris cf. *trifoliata.*
Sphenopteris sp. (showing fructification).
Odontopteris conwayi.
Alloiopteris (Corynopteris) serrula.
Pecopteris sp.
Mariopteris cf. *latifolia.*
Linopteris obliqua.
Dactylotheca sp. (?).
Corynopteris coralloides.
Alethopteris integra.
Trigonocarpon oblongum.
Cordaites borassifolius.
Artisia transversa.
Cordaianthus cordaicladus.
Polipterocarpus ornatus.

Summary.

From the foregoing list, it will be observed that 58 species are common to the Westphalian and Staffordian Series, 49 occur in the Westphalian alone, and 47 are confined to the Staffordian Series, thus making a total of 154.

[The new genera that appear in the foregoing list of species, which do not occur with the different genera enumerated in the tables of the ecology, were found in an older collection of 1500 specimens which were brought together before I began to work out the ecology. They are likewise not included in Tables I–XII or figs. 2–11.]

IV. DEDUCTIONS AS TO PHYSICAL CONDITIONS FROM THE FLORAL ANALYSES.

We now may consider the question, whether the different horizons which have been examined throw any light on the physical conditions of the past: in other words, whether the plant-remains found in the sediments give evidence of the distribution of the plants that actually flourished on the surface. If the question be answered in the affirmative, we can, with reservations, draw certain deductions from the data received.

It is only reasonable to infer that during the period which elapsed in forming the great thicknesses of shale and sandstone in the Coal Measures, the physical conditions varied as time went on.

The most significant fact that has impressed me in the examination of the different horizons is the sudden disappearance of the Filicales and Pteridosperms, as we ascend the series to the Two-Foot Nine and Pentre Seams, and the prominent appearance of the Lycopodiales in their place.

How is it that the Two-Foot Nine Seam only yields 24 specimens of Filicales and Pteridosperms, whereas it yields no fewer than 935 specimens belonging to the Lycopods? The Pentre Seam, again, produced 551 Filicales and Pteridosperms, but no fewer than 2051 Lycopods. It is very evident that some great physical changes occurred in Two-Foot Nine Seam and Pentre Seam times, and that the flora must have greatly altered in consequence.

For some reason or other, the Cordaitales and Equisetales are not so strongly influenced as the Filicales, Pteridosperms, and Lycopodiales by these changes, and it is fair to infer that the three last-mentioned groups were, during life, more sensitive to their surroundings than the first two.

Possibly it would be well to set forth here the converse evidence of the relative frequency of the Filicales and Pteridosperms in comparison with the Lycopodiales. The evidence found in the Two-Foot Nine and Pentre Seams and in the two succeeding and the two preceding seams, respectively, is very interesting. In the Nine-Foot and Six-Foot Seams the Lycopods number 196 in the former, and 32 in the latter; whereas the Filicales and Pteridosperms number 1624 in the Nine-Foot Seam, and 3127 in the Six-Foot Seam. This is a very striking contrast. The Lycopods have nearly disappeared in the two seams immediately above the Two-Foot Nine and Pentre Seams; and the Abergorky Seam, which occurs directly above the last-mentioned seam, only produced 9 specimens of these plant-remains. There are no fewer than 21 plants representing the Filicales and Pteridosperms in this seam. Again, in the No. 3 Rhondda Seam, the Lycopods were represented by only 14 specimens, whereas the Filicales and Pteridosperms were represented by 2341 specimens.

If the plant-bearing sediments on the sea-bottom are a faint reflex of the distribution of the plants covering the land-surface from which they were transported, due allowance being made for plants growing near the open seas and deltas, the instances above-mentioned imply the existence of a swampy surface with a flora of Lycopodiales flourishing during the period of the formation of the Two-Foot Nine and Pentre Seams. It will also be noticed that in the seams below and above, ferns and fernlike plants were more abundant and the Lycopods scantier, thus showing that the former flourished in profusion as a dry-land flora.

It is admitted that Equisetales grow in swampy ground and possibly on the slopes fringing the open seas or deltas, and it is further stated that Sphenophyllales are not essentially aquatic plants. The Lycopodiales were, however, particularly adapted for growth in mud or water, and Cordaitales also showed more vigour in a like habitat.

It is generally assumed that the Filicales and Pteridosperms represent a dry-land flora: hence, where these plant-remains are found in abundance in the shales, it is reasonable to conclude that, at that period, there was an extensive dry-land surface (which may have been due to upheaval), and, consequently, the conditions for the growth of these plants mentioned were congenial.

On the other hand, the Lycopodiales would require a swampy or marshy habitat; and one is justified in concluding that, in cases where ferns and fernlike plants become less numerous and Lycopodiales more numerous, there must have been a period of submergence of the land surface.

Appended are the views held by three distinguished living palæobotanists on the habitat of the different classes of plants:—

Equisetales.	Lycopodiales.	Filicales and Pteridosperms.	Cordaitales.
	View No. 1. Dr. R. Kidston, F.R.S. [*in litt.*].		
'Probably grew in wet places.' General remark:— 'Too much made of swampy conditions of the Coal Flora.'	'The Lycopods would not occupy such marshy ground.'	'Ferns and fernlike plants of Coal Age adapted for different conditions, some high and elevated lands; few damp and wet places; majority dry land.'	'Probably on the drier and elevated surface of the land, grew the Ferns and associated Pteridosperms.'
	View No. 2. Dr. D. H. Scott, F.R.S.		
'Roots of Calamites, like the roots of plants of to-day, adapted for growth in soft mud with a lacunar internal structure (soft-celled).' General remark:— 'Complete sterility of the upland did not appeal to the author as it did to Grand' Eury.'	General remarks:— 'General conditions of life fundamentally the same. 'Roots of Lycopods with the same internal character as *Calamites*, hence wet places and mud (swampy conditions). 'Leaves of *Lepidodendron* and *Sigillaria* being thick, with stomata hidden in deep channels, suggest wet and dry conditions alternating, like in mangrove swamps.'	'Some of the ferns and fernlike seeds blend with thick fleshy leaflets, with a structure suggesting dry land and certainly not wet surroundings.'	'Internal structure showed little or no evidence or anatomical indication of a swampy environment.'
	View No. 3. Dr. Marie C. Stopes [*in litt.*].		
'I think, also, that the Equisetales grew in swamps like the Lycopods: there is no evidence that they grew in high land.'	'Adapted for growth in water and mud, essentially swampy.'	'Adapted for both sets of conditions. Hard leaves like *Pecopteris*, *Alethopteris*, suitable for dry and elevated lands.'	'Definitely a dry-land flora and one of even elevated land.'

If we adopt a balance of the three opinions quoted above, it would seem that the probable conditions of the land-surface prevailing during the sedimentation of the shales of the ten horizons dealt with in this paper might be expressed in the following table.

Name of seam.	*Percentage composition of flora.*	*Probable physical conditions.*
Five-Foot Seam.........	Equisetales ...... 30·34 p. c. Lycopodiales ... 0·21 p. c. Filicales and Pteridosperms 24·46 p. c. Cordaitales ...... 43·84 p. c.	A large extent of dry land, and possibly upland. The fact that Lycopodiales are weak suggests a restricted area of swamps.
Middle Yard Seam ...	Equisetales ...... 72·96 p. c. Sphenophyllales 0·18 p. c. Lycopodiales ... 0·49 p. c. Filicales and Pteridosperms 24·41 p. c. Cordaitales ...... 1·35 p. c.	The conditions must have been very similar to the period of the formation of the Five-Foot Seam. It will be noticed that the Lycopods are rare, and that dry-land vegetation is much in evidence.
Upper Yard Seam......	Equisetales ...... 29·04 p. c. Lycopodiales ... 9·82 p. c. Filicales and Pteridosperms 37·68 p. c. Cordaitales ...... 6·24 p. c.	There has been a slight change in the land-surface. Dry-land flora increases, probably owing to the uplift of the land surface. The fact that the Lycopods are more abundant suggests more swampy areas in places.
Nine-Foot Seam	Equisetales ...... 49·74 p. c. Lycopodiales ... 3·33 p. c. Filicales and Pteridosperms 27·55 p. c. Cordaitales ...... 17·03 p. c.	Dry-land plants are rarer in this seam than in the Upper Yard Seam, and the Lycopods are also fewer in number. We may infer that the land-surface was depressed and of no high altitude, yet with swampy areas less prevalent.
Six-Foot Seam	Equisetales ...... 39·94 p. c. Lycopodiales ... 0·44 p. c. Filicales and Pteridosperms 43·77 p. c. Cordaitales ...... 14·15 p. c.	This period includes possibly the highest elevation of the land-surface. The ferns and fernlike plants are dominating the other classes of plants. Swampy areas are limited, hence the rarity of Lycopods.
Two-Foot Nine Seam.	Equisetales ...... 5·96 p. c. Lycopodiales ... 66·38 p. c. Filicales and Pteridosperms 1·70 p. c. Cordaitales ...... 25·13 p. c.	The inference here is, that there was an extensive low land-surface covered with huge marshes. The uplands were limited to small areas, upon which the few Filicales and Pteridosperms flourished. The chances of the preservation of the latter plants were only one in forty, as the evidence shows.

Name of seam.	*Percentage composition of flora.*	*Probable physical conditions.*
Pentre Seam	Equisetales ...... 25·99 p. c. Sphenophyllales 6·49 p. c. Lycopodiales ... 38·71 p. c. Filicales and Pteridosperms 9·97 p. c. Cordaitales ...... 18·68 p. c.	Lowland conditions prevailed, with slight undulations bordering large marshes. The increase in the number of Filicales and Pteridosperms is marked, and suggests a period of gradual upheaval of the land-surface.
Abergorky Seam	Equisetales ...... 82·41 p. c. Sphenophyllales 0·40 p. c. Lycopodiales ... 0·21 p. c. Filicales and Pteridosperms 5·13 p. c. Cordaitales ...... 9·6 p. c.	An undulating land-surface with very few marshes. The elevations could not have been of any great extent, as the ferns and fern-like plants are scarce. It does not always follow that the general outline of the surface, although of lowland character, shows the existence of marshy conditions, as the Lycopods are rare.
No. 3 Rhondda Seam .	Equisetales ...... 37·19 p. c. Sphenophyllales 1·09 p. c. Lycopodiales ... 0·25 p. c. Filicales and Pteridosperms 42·13 p. c. Cordaitales ...... 20·10 p. c.	A period of rising land-surface resulting in high elevations which would be well clothed with ferns and fernlike plants. Their preponderance over the other classes would be great under such conditions. Marshes of small area would be met with in the tracts of low land where the Lycopods flourish. A marked contrast is noticeable here between the Lycopods and the fernlike plants.
No. 2 Rhondda Seam .	Equisetales ...... 41·56 p. c. Sphenophyllales 6·64 p. c. Lycopodiales ... 1·23 p. c. Filicales and Pteridosperms 35·89 p. c. Cordaitales ...... 14·68 p. c.	A slightly depressed land surface prevailed here, as compared with No. 3 Rhondda Seam times. The marshy areas were not very prevalent, and the Lycopods are still rare. A period of possibly subsiding land-surface occurs, which gives rise to a gradual decrease in the growth of ferns and fernlike plants.

It will be observed from the foregoing synopsis that the Equisetales dominate the other classes, four times, in the Middle Yard, Nine-Foot, Abergorky, and No. 2 Rhondda Seams.

The Sphenophyllales are rare, and are only met with at five horizons, namely, the Middle Yard, Pentre, Abergorky, No. 3 Rhondda, and No. 2 Rhondda Seams.

The Lycopodiales dominate the other classes twice, in the Two-Foot Nine and Pentre Seams.

Filicales and Pteridosperms dominate other classes of plants three times, in the Upper Yard, Six-Foot, and No. 3 Rhondda Seams.

Cordaitales dominate the other classes once only, in the Five-Foot Seam, the lowest horizon.

It is found that, when a genus becomes common in the field, the number of the species generally lessens. For instance, if we take *Calamites*, *Asterophyllites*, and *Annularia* from the Equisetales, the two genera *Lepidodendron* and *Sigillaria* from the Lycopodiales, and the genera *Neuropteris*, *Sphenopteris*, *Pecopteris*, *Mariopteris*, and *Alethopteris* of the fern and fernlike plants, the general graphs show an increased number of these different genera of plants and a decrease in the number of species belonging to the same genus at the same horizon.

Taking the ten horizons on which the ecology and the graph of convergence and divergence of species has been based, the two graphs show that there is an increase in the number of species and a decrease in the number of the corresponding genus in the field. This has happened at the ten horizons on 34 occasions. The converse of this statement: that is, a decrease in the number of species and an increase in the genera, has occurred on 11 occasions. An increase of species following an increase of genera happens on 13 occasions, and a decrease of species followed by a decrease of genera occurs on 14 occasions.

The question that naturally arises from the preceding statements is, whether plants would have a tendency to remain quiescent in development of differentiation during a period that was favourable for their existence; and also, would unfavourable physical conditions cause the plants to make an extra effort towards adaptation and bring about the development of new species?

V. Stratigraphical Considerations: the Existence of a Break between the Westphalian and the Staffordian Series.

With the lithological change in the strata at the No. 3 Rhondda Seam, where sandstones begin to take the place of shales, it is observed that pebbles of quartz, sandstone, and coal occur as thin conglomerates of a lenticular character. Even the sandstones contain smooth and well-rounded pebbles of coal, varying in size from a thrush's egg to a big orange.

Four samples of these coal-pebbles from the sandstone above No. 2 Rhondda Seam, and three samples of No. 2 Rhondda coal which lies immediately below the sandstone from which the coal-pebbles were taken, have been subjected to chemical analysis by Mr. E. M. Bowen.

The samples of coal-pebbles, like the samples of No. 2 Rhondda coal itself, were found to be coking coal. The analyses varied in the coal-pebbles, and are as follows:—

	Coal-Pebbles.				Sample of Coal from No. 2 Rhondda Seam.			
	Ash.	*Volatile matter.*	*Sulphur.*	*Fixed carbon.*	*Ash.*	*Volatile matter.*	*Sulphur.*	*Fixed carbon.*
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
I.......	25·70	25·10	1·29	49·20	4·23	24·82	1·38	70·95
II.......	21·20	22·20	1·43	56·60	2·85	25·60	1·331	71·55
III.......	5·60	24·00	1·47	70·40	2·60	27·20	1·337	70·20
IV.......	3·40	23·30	1·28	73·30				

If we believe that the coal-pebbles were originally pellets of peaty matter rolled about under littoral conditions, then we may enquire how it is that the coal-pebbles now found are composed of pure coal, and are free from any grains of sand embedded in its mass.

On the other hand, if we are led to believe that the coal-pebbles, owing to their rounded and smooth surfaces, have been derived from coal-seams which had already hardened into such a state as to allow of the coal being transported by the action of water from the position in which it originally rested to the place where it is now found, then we must conclude that the coal-seam itself was, when degradation took place, composed of young coal. The chemical analyses show that the amount of fixed carbon and ash varied in the coal-pebbles; but the general results prove that in quality the coal was very similar to the No. 2 Rhondda coal.

If the origin of these coal-pebbles is to be sought on the latter hypothesis, then we must conclude that a considerable lapse of time occurred between the deposition of No. 3 and No. 2 Rhondda Seams and the seams below, because the interval must have been such as to allow the peaty matter to harden into the solid state of coal by the pressure of sediments now forming the strata above the seams. This, in itself, would imply ancient sea-floors with their sediments hardened into a compact mass, their uplift into a land surface, again to be channelled out by the action of water so as to allow of these coal-pebbles travelling from their original positions to the position in which they are now found. Assuming that this was really the case, then we have, possibly, some answer to the great increase in the number of species of plants at this juncture: namely, at the horizons of No. 3 and No. 2 Rhondda Seams, because we find no fewer than 43 new species occurring here. Stated briefly, there is at the base of the Staffordian Series a lithological change, sandstones taking the place of shales: the former contain smooth and rounded coal-pebbles, the plant-remains from which are characterized by an inrush of new species. A question that naturally arises is—Would the interval of time at this point represent a geological break of sorts; and again, would the increase of species represent a palæontological break?

I believe that some determining factors operated between Westphalian and Staffordian times, and if evidence can be procured over an extensive area to establish the fact that derived coal-

pebbles occur in the series at this juncture, accompanied by a great increase of new species, we could fairly conclude that both geological and palæontological breaks occurred.

VI. Concluding Remarks.

The difficulty of arriving at a reasonable conclusion as to past physical conditions will always remain. We notice from the evidence set forth that, throughout the ten horizons, there is a good representation of marsh or swamp flora in the Equisetales, also an even more persistent representation of a dry-land flora in the Cordaitales throughout these horizons. On the other hand, there is a dry-land flora, as represented by the ferns and fernlike plants notably weak; whereas the Lycopods (a swamp flora) are abundant at the time when the ferns and fernlike plants were extremely rare. Possibly the Equisetales always managed to survive, even when great areas of elevated land-surface prevailed, clothing perhaps the margins of the drainage systems, such as the rivers, deltas, and the slopes near the open seas. Again, the Cordaitales possibly were very adaptable to altered physical conditions. It would be well to state here that, whatever may be the reason, the association of Cordaite-leaves and *Calamites* was of common occurrence throughout in the same blocks of shale. On the other hand, the Lycopods were not persistent (as already stated), and only appeared in force at two horizons. A significant fact is that the ferns and fernlike plants were nearly eliminated at this juncture. A further point worthy of consideration is the fact that prior to and after this period favouring the Lycopods, a goodly number of ferns and fernlike plants appeared, whereas the Lycopods were notably rare. Another point worthy of notice is the fact that, when Lycopods were commonly found, their cones were frequently associated in the same slabs of shale. It is quite natural that, as the stems and shoots of the Lycopods were transported from the point where they grew to the point where they now rest in the sediments, the cones should also accompany them.

It is reasonable to believe that, when possibly a preponderance of dry-land flora existed in the past, their balance, when examined in the shales, from a point of distribution, would greatly alter, owing to the favoured position of plants which grew near running water, favoured in regard to future preservation of their remains.

Possibly we may conclude that the key to the problem of past physical conditions is found in the ferns and fernlike plants and the Lycopods. They doubtless reacted one on the other, coincidently with the physical changes. If we believe that, generally speaking, the ferns and fernlike plants were on the whole a dry-land flora, and that the Lycopods represented a swamp flora, then we are driven to the conclusion that upland conditions prevailed from Five-Foot Seam times to Six-Foot Seam times, followed by a cycle of submergence of the elevated

land producing extensive open marshes. This prolonged period ranged from Two-Foot Nine Seam to Pentre Seam times; then a cycle occurred with an emerging land-surface culminating in upland conditions. This happened during Abergorky Seam, No. 3 Rhondda Seam, and No. 2 Rhondda Seam times.

The variation in the different classes of plants as to distribution would alter in the sediments forming the shales of the ten horizons, and conform in a greater or less degree with the gradual changes which took place in the land-surface. The sea-bottoms, with their sediments and plant-remains, are always a faint reflex of the distribution of these plants on the surface of the land.

There is no doubt that too much stress has been laid on the swampy conditions prevalent during Coal-Measure times, for there is good reason to believe that elevated land-surfaces were to be found then as now, and that the upland portions were clothed with Cordaitales and ferns and fernlike plants. It is difficult to conceive that the higher portions of the upland surface in Coal-Measure times were entirely devoid of vegetation.

The results of this investigation may be summarized as follows:—

(1) Although plants show great similarity over a considerable area at the same horizon, they show great dissimilarity over small vertical distances, that is, from shales overlying one seam to another.

(2) A period of Lycopods, especially conspicuous during Two-Foot Nine and Pentre Seam times, with a paucity of ferns and fernlike plants.

(3) A period before and after, when ferns and fernlike plants occurred in abundance, with Lycopods rare.

(4) The comparative persistence of Cordaitales and Equisetales throughout all the horizons.

(5) A lack of persistency of the Filicales and Pteridosperms and of the Lycopods. One class was found to react upon the other, thus causing one to be predominant, whereas the other class was very scanty and *vice versa*.

(6) The common association of *Calamites* and *Cordaites* leaves in the same slabs of shale, and also the common association of *Lepidodendron* and *Lepidostrobus* on the same blocks of shale.

(7) A cycle of depressed land-surface seemingly prevailed during Two-Foot Nine and Pentre Seam times, possibly forming extensive open marshes which would favour the Lycopods; whereas, before and after this cycle of depression, more elevated land-surfaces prevailed, favouring the ferns and fernlike plants.

(8) When a genus proved common in the field, the number of species contained within that genus was found to be decreasing in the ratio of 5 to 3.

(9) There was probably a geological break at the time of formation of the coal-pebbles, and also a palæontological break at the base of the Staffordian Series. Coal-pebbles suggest the former break, and the 43 new species of plants suggest the latter.

(10) Forty-five new species of plants have been added to the records of the South Wales Coalfield, and seven new species not previously recorded in Britain have been found. One new type of insect was discovered.

EXPLANATION OF PLATE II.

General graph showing the distribution of plants in relation to time and space in the Westphalian Series, and in the lower part of the Staffordian Series, of Clydach Vale and Gilfach Goch (Glamorgan).

Discussion.

Prof. P. F. Kendall said that the Author had devised and applied a novel and valuable method of research into the plant-distribution in the Coal Measures, and he was to be congratulated on the accomplishment of an arduous task.

He enquired whether the samples of shale examined constituted the immediate roof of the seams, that was, the layers within a few inches of the seam. The speaker believed that these would in many cases yield evidence of the last 'crop' that contributed to the growing seam.

In the Westphalian measures of Yorkshire the roofs of many seams—for example, the Silkstone, Middleton Main, Haigh Moor, and Parkgate—contained prostrate stems of *Sigillaria* and 'pot-holes'; the casts of hollow tree-stumps were also of frequent occurrence in similar positions. The speaker had never observed Lepidodendroid trunks along with them: on the other hand, the roof of the Barnsley Bed was renowned as a source of fine fernlike plants.

With regard to the Author's conjectures respecting the habitat of the different types, he remarked that, whereas Lycopods commonly, and Calamites more rarely, were to be found rooted in the position of growth, he could not recall a single instance in which unequivocal evidence of fernlike plants in the attitude of growth had come under his observation.

He enquired whether the Author had made any examination of thin sections of the coal-seams. This method of study would throw light upon the question whether the plants found in the intervening measures were similar to those composing the coal. The speaker had been enabled, by the generosity of the owners of collieries in Yorkshire, to obtain a unique suite of thin sections, exhibiting the whole thickness from floor to roof of the Barnsley Bed, from six pits, and he had hopes of ultimately covering the entire field from Leeds to Nottingham.

It was to be hoped that the Author's methods might be applied over a yet wider area in South Wales, in order to see whether his results gave any support to the view that the transition from bituminous coal to anthracite was in any way related to the ecology of the constituent flora.

The occurrence of coal-pebbles at the base of the Staffordian measures was a fact of great interest; and, from an inspection of the specimens exhibited, he quite agreed that they had not been in the condition of peat when they were formed. It had been argued, in other instances, that the mineralization must have been completed prior to the enclosure of the pebbles in the surrounding

sandstone, on the ground that otherwise the shrinkage due to loss of volatile constituents would have caused the pebble to contract away from the surrounding matrix; this contention assumed the early consolidation of the Coal Measures, but the analogy of the Tertiary deposits of the Isle of Wight shows that strata containing beds of coal or lignite may remain unconsolidated for long periods; furthermore, the process of conversion of vegetable matter into lignite may be accomplished in a very short time: for instance, lignite of Pleistocene age in Alaska had been described.

Dr. Marie Stopes expressed her appreciation of the paper, but as she had not yet seen the manuscript, and it contained so vast an amount of detail, she found it impossible to discuss it fully. She wished to accentuate the importance of the work done, and also its magnitude; the task of recording and identifying 45,000 specimens in the field was truly an immense labour, and this careful statistical work had not hitherto been done in connexion with fossil plants.

As a result of the Author's arduous work, the speaker had hoped that one special point might be illuminated, but, through no fault of his own, it was not yet cleared up. The coal-pebbles described, upon which Prof. Kendall had commented, were naturally of considerable interest; but they indicated a physical break in the deposition.

She had hoped that the Author might bring facts to light which would illustrate the phylogenetic evolution of the various species within the genera; but, owing to this break in continuous deposition, such results could not be expected. She urged other colliery-managers, whose seams showed good attendant fossils and in beds passing without physical break from one major division to another, to spend some years collecting such detailed statistical evidence as would illustrate the phylogeny of the species within the well-known genera.

In conclusion, the speaker hoped that the Author's careful work would be followed by similar statistical enumeration of the distribution of fossil plants. She warmly congratulated him on his enthusiasm, and on the successful accomplishment of his arduous task.

Mr. E. A. Martin remarked that, if ferns and Pteridosperms indicated elevated land, they must have undergone much drifting to have become embedded in the shales at the level of the marshes. Did they show any greater degree of drifting than other forms of vegetation? The coal-pebbles did not, in his opinion, indicate great lapse of time between the deposition of the coal and the sandstone, but rather that the formation of coal was a more rapid process than was generally thought to be the case.

Prof. A. H. Cox wished, as a worker in South Wales, to add his congratulations to those of previous speakers The Author had devoted 25 years to the assembling of the material on which the paper was based, and the results were many-sided in their importance. He felt that South Wales was fortunate in having a

worker such as the Author, who was prepared to sacrifice much for the accomplishment of his investigations.

The AUTHOR, in reply, stated that trunks from 18 inches to 2 feet in diameter, with leaf-scars of *Lepidodendron* well preserved, were found in the Seven-Foot Seam at the Cambrian Collieries, Clydach Vale. The shales constituting the 'roof' immediately above the seams had been examined, but they generally proved to be destitute of plant-remains Usually, the fossiliferous beds were situated about 6 feet or so above. He wished it to be understood that unfossiliferous beds occupied the positions between all the fossiliferous horizons that he had examined.

In conclusion, he thanked the President and Fellows for their reception of his paper.

[**May 13th, 1921.**]

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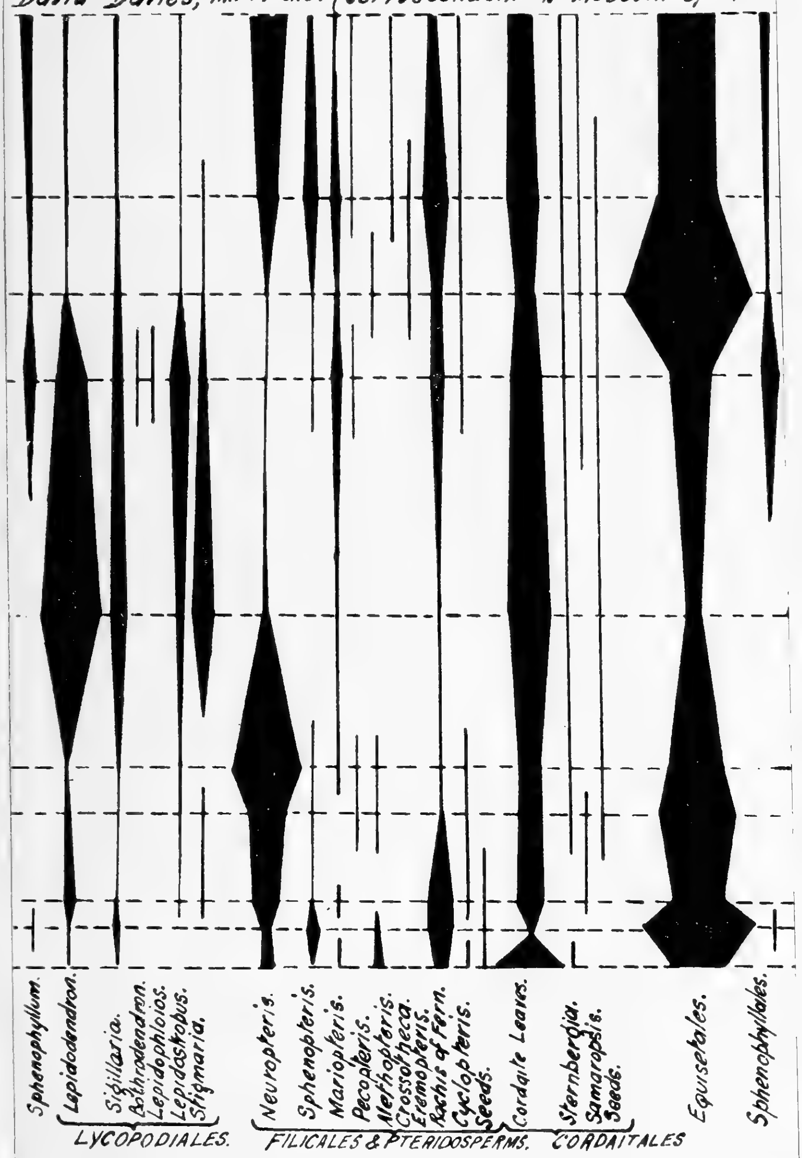
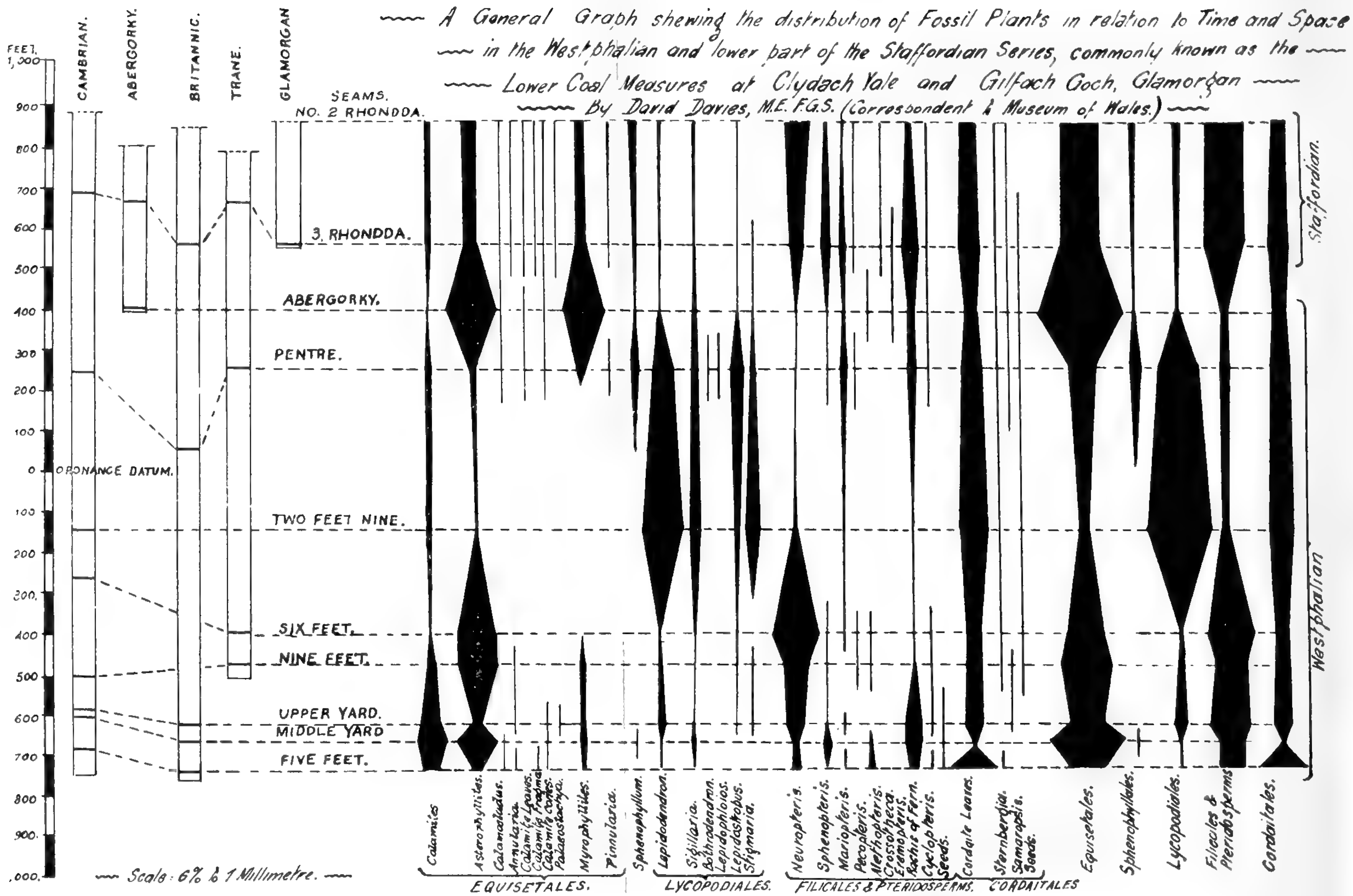
David Davies, M.E. F.G.S. (Correspondent & Museum of Wale




A General Graph shewing the distribution of Fossil Plants in relation to Time and Space in the Westphalian and lower part of the Staffordian Series, commonly known as the Lower Coal Measures at Clydach Vale and Gilfach Goch, Glamorgan
By David Davies, M.E. F.G.S. (Correspondent & Museum of Wales.)
FEET.
CAMBRIAN.
ABERGORKY.
BRITANNIC.
TRANE.
GLAMORGAN
SEAMS.
NO. 2 RHONDDA.
3. RHONDDA.
ABERGORKY.
PENTRE.
ORDNANCE DATUM.
TWO FEET NINE.
SIX FEET.
NINE FEET.
UPPER YARD.
MIDDLE YARD
FIVE FEET.
Staffordian.
Westphalian
Scale: 6⅔ to 1 Millimetre.
Calamites
Asterophyllites.
Calamocladus.
Annularia.
Palaeostachya.
Myriophyllites.
Pinnularia.
Sphenophyllum.
Lepidodendron.
Sigillaria.
Bothrodendron.
Lepidophloios.
Lepidostrobus.
Stigmaria.
Neuropteris.
Sphenopteris.
Mariopteris.
Pecopteris.
Alethopteris.
Crossotheca.
Eremopteris.
Rachis of Fern.
Cyclopteris.
Seeds.
Cordaite Leaves.
Sternbergia.
Samaropsis.
Seeds.
Equisetales.
Sphenophyllales.
Lycopodiales.
Filicales & Pteridosperms
Cordaitales.
EQUISETALES.
LYCOPODIALES.
FILICALES & PTERIDOSPERMS.
CORDAITALES

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[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

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Part 2.

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OF THE

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THE PERMANENT SECRETARY

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ORDINARY MEETINGS OF THE GEOLOGICAL SOCIETY TO BE HELD AT BURLINGTON HOUSE.

Session 1921–1922.

1921.		
Wednesday,	November	9*—23
„	December	7 —21*
1922.		
Wednesday,	January	4*—18*
„	February (*Anniversary Meeting*, Friday, February 17th)	1*—22*
„	March	8 —22*
„	April	12
„	May	10*—24
„	June	14*—28

[*Business will commence at 5.30 p.m. precisely.*]

The asterisks denote the dates on which the Council will meet.

5. *The* GRANITE-GNEISSES *of* SOUTHERN EYRE PENINSULA (SOUTH AUSTRALIA) *and their* ASSOCIATED AMPHIBOLITES.

By CECIL EDGAR TILLEY, B.Sc., A.I.C. (Communicated by Dr. H. H. THOMAS, M.A., Sec.G.S. Read February 2nd, 1921.)

CONTENTS.

I. INTRODUCTION.

THE basement platform which forms the foundation of Southern Eyre Peninsula, and on which the much younger Tertiary and Recent sediments repose, consists of a complex of igneous and metamorphic rocks, which in their lithological and petrographical characters bear not only a remarkable resemblance to rocks of known Pre-Cambrian age in other parts of the State, but also to the well-known Pre-Cambrian tracts in other regions of the world.

The evidences for the Pre-Cambrian age of the Eyre Peninsula rocks cannot rest on palæontological evidence, for there are no

known deposits of Lower Palæozoic age that have been recognized within the area. The data from which the Pre-Cambrian age is deduced are, therefore, of a comparative kind.

The older rock series of Yorke Peninsula to which these Eyrian rocks bear a close lithological and petrographical resemblance are of definite Pre-Cambrian age, as proved by the presence of Cambrian sediments on an eroded platform of the series, in the Moonta and Wallaroo region. Apart from this local correlation, the complex bears a noteworthy similarity to the Pre-Cambrian tracts of the Northern Hemisphere, and to none more than the Laurentian of Canada.

Superposed with a marked angular unconformity on the metamorphosed members of this older complex, and resting horizontally on the deeply-eroded igneous types, are Upper Tertiary sands and travertine. These deposits form a mantle to a considerable portion of the region, and hinder the study of the older series over large areas of country. Inland, in the hilly regions of the hundreds of Warrow and Hutchison, and to a less extent in the hundreds of Louth and Lincoln, the older rocks are stripped of this mantle, permitting a study of the complex. The best exposures, however, are displayed along the coastline, where detailed studies can be made on the wave-swept platforms which fringe the coast. Here the older rocks are usually within 100 feet of sea-level, and are covered unconformably by consolidated sands of æolian origin.

Precipitous cliffs are often developed, and occur especially in the hundreds of Flinders and Sleaford, where the coastal cliffs attain a height of from 300 to 400 feet. The older rocks contribute but a small part to this elevation.

Previous Literature.

The literature bearing on the geological structure of Southern Eyre Peninsula is principally to be found in the publications of the Geological Survey of South Australia.

As the Survey investigations have been primarily made in order to determine the possibility of the discovery of petroleum in this area, but little detailed work has been done on the older complex, and, so far as petrological investigation is concerned, the field up to the time of the present enquiry can be regarded as untouched. A summary of the available geological literature of the area is appended to this paper.

II. The Divisions of the Pre-Cambrian of Southern Eyre Peninsula.

The division of the complex into well-characterized groups or series of rocks is largely hampered by the fact that sections of these rocks, continuous over large areas, are seldom to be obtained. There are, however, despite this dominant mantle of calcareous

sands and lateritic ironstone, certain features which can be singled out as characterizing types of rocks, and the following divisions or series are recognized:—(*a*) The Hutchison Series, (*b*) The Flinders Series, (*c*) The Warrow Series, and (*d*) The Dutton Series.

The division calling especially for treatment in this paper is the Flinders Series; but a brief statement is necessary concerning the nature and constitution of the remaining series.

(*a*) The Hutchison Series.

Some members of this series have already been described: namely, the dolomites and calc-magnesian silicate-rocks,[1] the paragneisses,[2] and the graphite-rocks.[3] This formation is predominantly of sedimentary origin.

The sequence of rocks, and further subdivision of this series, if ever possible, must await a detailed examination of the hundred of Hutchison, and its northward extension, where these rocks are extensively developed.

The Sleaford-Bay area gives some idea of the complexity of this formation, which has been invaded and cut up by later igneous intrusions.

The strata strike in a north-and-south direction, swinging to a north-easterly direction in the northern exposures. This may be appropriately called the 'graphite line,' as the occurrence of graphite is, so far as is known, confined to the metamorphosed sediments which are grouped within the Hutchison Series.

(*b*) The Flinders Series.

This is the most widespread member of the group. It consists of a complex of igneous rocks: granites and gneisses with associated basic rocks, amphibolites, hornblende-schists, and pyroxene-granulites.

Its relation to the Hutchison Series is always of the intrusive kind. A section has been given, in the papers to which reference is made above, of the Hutchison Series invaded and metamorphosed by sills of the Flinders gneisses.

(*c*) The Warrow Series.

This is a metamorphosed sequence of sediments, principally developed in the hundreds of Warrow and Lake Wangary. The rocks are quartzites, slates, and mica-schists.

This group is distinct from the Hutchison Series, its chief

[1] Geol. Mag. 1920, pp. 449–62, 492–500.
[2] *Ibid.* 1921, p. 251.
[3] 'Economic Geology' 1921, pp. 184–98.

characteristic being a great thickness of massive quartzites, rocks which form inconspicuous members of the Hutchison Series.

(*d*) The Dutton Series.

The Warrow Series has been metamorphosed by a later extrusion of granites, developed in the hundred of Warrow. These granites are distinguished by the development of abundant tourmaline in their more acid differentiates. A zone of lit-par-lit injection along the contact has resulted in the development of injection-gneisses from the Warrow schists.

The serial sequence given above is one of decreasing geological antiquity, and the oldest group of rocks developed in the area is thus of sedimentary origin.

There can be but little doubt as to the Pre-Cambrian age of the Hutchison, Flinders, and Warrow Series, but the inclusion of the Dutton Series within the Pre-Cambrian is tentative only, and with an increasing knowledge of the igneous history of South Australia it may be relegated to the Lower Palæozoic.

III. The Flinders Series.

(*a*) Geographical Extent.

The members of this series occupy the most extensive area of any of the Pre-Cambrian groups of rocks in Southern Eyre Peninsula. In the south, they are developed in the hundreds of Flinders and Sleaford. Starting from their westernmost exposure at the Red Banks on the west coast of the hundred of Sleaford, they crop out along the coastline in an easterly direction past Cape Wiles to Sleaford Bay, where the members of the Hutchison Series intervene in a half-mile section. The coastline farther east consists of Recent calcareous sands until the Curta Rocks are reached, adjacent to the coast of the hundred of Flinders, when the gneisses reappear. They are well developed farther south on the fringe near West Point and Cape Catastrophe, and form the eastern coast of the hundred of Flinders.

The coastline of the hundred of Lincoln, as also Boston Island, consists of these rocks, and they are particularly well exposed on the shore-line at Kirton Point, Port Lincoln. The minor peninsula of Point Boston is formed of these gneisses, as also the island of Louth and the promontory of Bolingbroke in the hundred of Louth. In the hundred of Hutchison, they crop out along the coast south of Tumby Bay and at Cape Euler.

The inland exposures of the gneisses are but few and isolated. The prominent hills behind Memory Cove (hundred of Flinders) consist of these rocks, and in the hundred of Lincoln they are well exposed in the monadnocks of Cobbler's Hill, North Hill, and Winter Hill, occupying also an area behind Port Lincoln itself.

In the hundred of Hutchison, outcrops are found along the Port-Lincoln road, and, associated with members of the Hutchison Series, they crop out in the hilly region west of Tumby Bay.

Their extensions north of the hundred of Hutchison have not been traced. The islands which fringe the eastern coast of the peninsula are formed of gneisses of the Flinders Series, notably the Cape-Catastrophe group, and the Neptunes. They are largely covered by recent calcareous sands. (See map, fig. 1.)

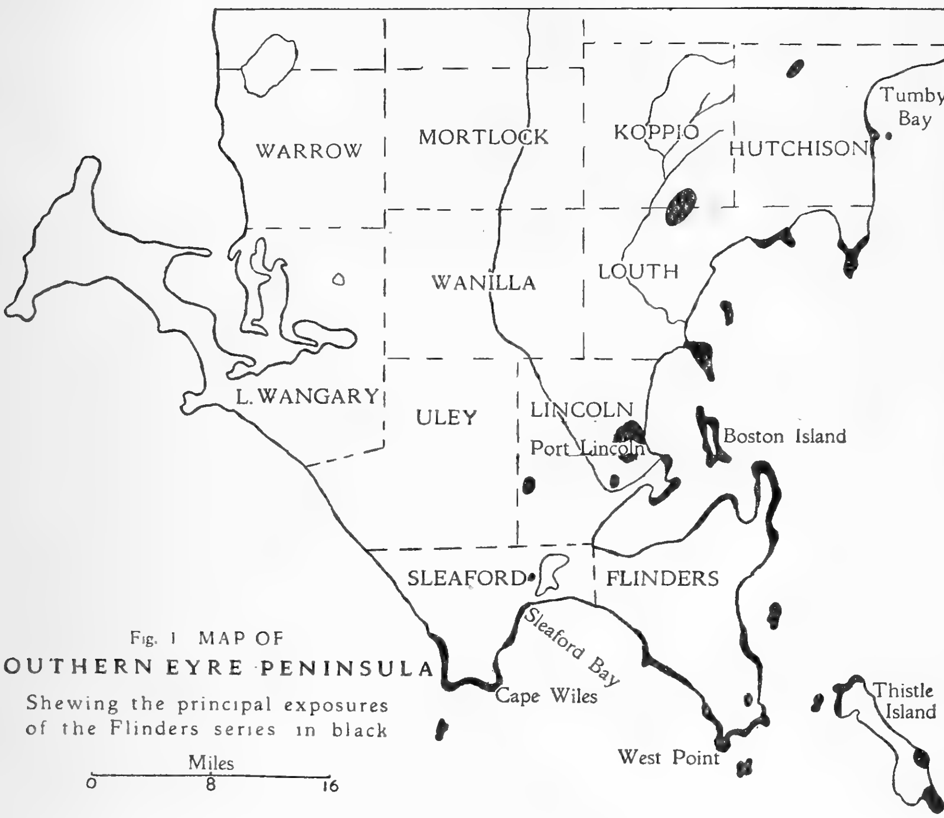


Fig. 1 MAP OF SOUTHERN EYRE PENINSULA Shewing the principal exposures of the Flinders series in black

(b) Constitution.

A diversity of rock-type is comprised within the group. The members include hornblende- and biotite-granite-gneisses, often with a typical augen-structure, hypersthene- and diopside-granites of the charnockite type, pegmatites and aplites, and porphyritic types, the pegmatitic varieties being especially characterized by hornblende.

This acid complex carries intercalated bands of basic rocks, amphibolites, hornblende-schists, pyroxene-granulites, etc.

The gneissic structure which is the dominant characteristic of the granites is a primary structure, and represents a foliation imparted to the rocks during their consolidation.

For descriptive purposes the basic bands of the Flinders gneiss can be subdivided as follows:—

(1) Amphibolites and hornblende-schists.
(2) Pyroxene-bearing types (pyroxene-granulites).
(3) Bands of metamorphosed sediments.
(4) Metadolerites.

Dealing now with the broader features of the Flinders Series, I may point out that in the southern area the foliation of the granite-gneisses is predominantly north and south, with a variable swing to a little east or west of this prevailing direction. The dip or inclination of the foliation is at a high angle, in some cases practically vertical, or at a high angle to the west. In the northern area, the foliation of the gneisses has swung to the north-east, but the steeply-dipping foliation-planes are still developed.

The abundant development of this gneissic foliation shows that crystallization accompanied movement of the magma. These movements in the magma were not limited to the period in which the magma was largely liquid, but continued during crystallization, with consequent orientation of elongate crystals such as porphyritic felspars, biotite, and hornblende, and was progressing when crystallization had well advanced.

There are evidences of protoclastic structures to be met with in the different areas. Such movements in the later stages, with a growing rigidity of the mass, may be developed in directions oblique to the main direction of foliation, and along these planes of shear the gneissic foliation is locally deflected, the plane of shear being represented by a finer granulitic type. Such features indicate local movement when the gneiss had reached a stage of considerable viscosity.

The gneissic foliation is not a constant feature of the granites. An imperceptible gradation from perfectly massive types through varieties in which a foliated structure is just discernible, to strongly developed augen-gneisses or banded types can be traced. The separation of different types is, therefore, precluded, and the gneissic foliation which is set up is not wholly assignable to any one cause, as will be indicated hereunder. The massive and foliated types are different phases of the one rock-mass. In some cases the dominant gneissic structure can be ascribed to hybridization, or to the disruption of a pre-existing dark band through intimate penetration by the later acid intrusion. It is quite clear that the gneissic structure cannot be regarded in any way as a metamorphic feature, and the foliation is essentially that described for primary gneisses of other regions.

The granite-gneisses have been intersected by a later though comagmatic series of pegmatite- and aplite-dykes, which often show no trace of gneissic foliation, and cut the gneisses at right angles to the prevailing direction of foliation, the east-and-west joint-planes being often utilized as fissures.

As to the dark basic bands which everywhere are seen intercalated in the acid gneisses, those which are now essentially amphibolites or hornblende-schists are the most numerous.

I have already referred (in another place) to the occurrence of undoubted sediments as rift-blocks derived from the Hutchison Series. The best example of this type is the band of diopside-rock which occurs in the garnet-gneisses of Fishery Bay. This band, oriented with its longer axis parallel to the prevailing gneissic foliation, is identical with the diopside-rocks developed by silicification of dolomites of the Hutchison Series 3 miles away to the north-east. It has been invaded by felspathic solutions from the granite, and is clearly an inclusion in the gneiss.

The amphibolites are dark rocks occurring as well-defined bands in the gneiss, and developed with their longer axes parallel to the foliation in the gneiss. Large masses of quite irregular shape are, however, not uncommon, and, as seen surrounded on all sides by acid gneisses, are convincing evidence that they are of anterior origin.

In those long and narrow bands, a foliation is often developed, and the amphibolites then pass into hornblende-schists. The foliation is always parallel to the longer axes of these bands, and to the gneissic foliation, except where the band has been broken up by the invading magma and separated into fragments by the magmatic movement.

IV. The Relationships of the Amphibolites to the Associated Gneisses.

All the available evidence goes to show that the amphibolites developed in the gneisses—with certain exceptions to be mentioned later—are of anterior origin to the gneisses. The evidence on which this inference is based will now be described.

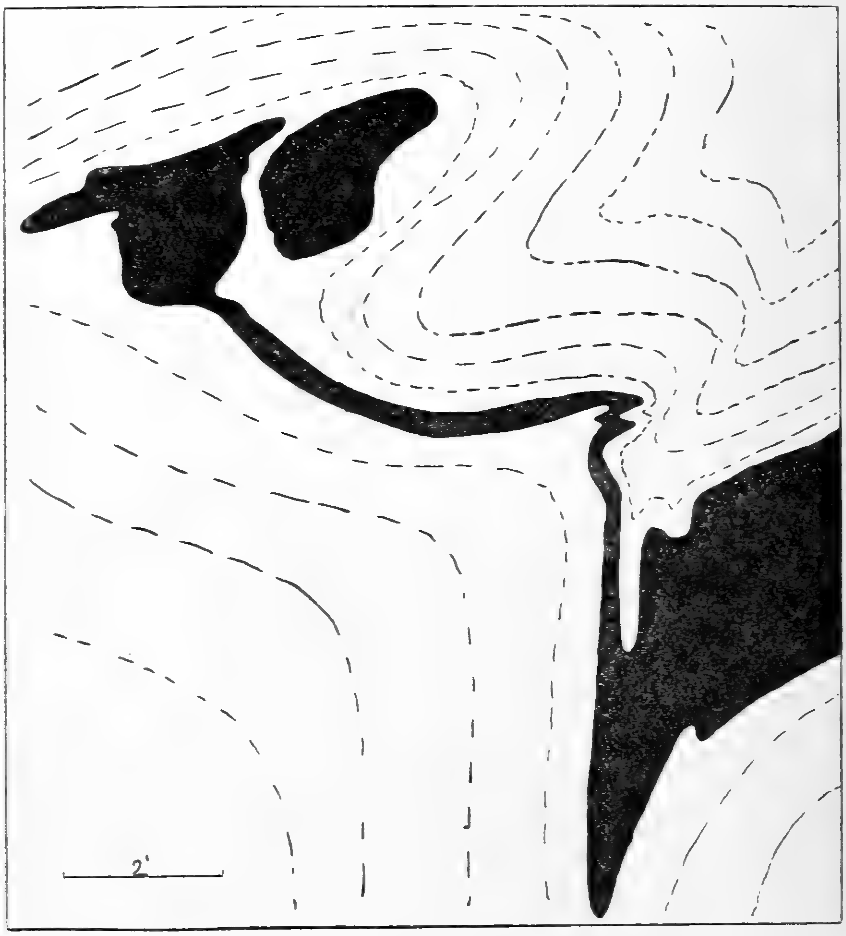
The amphibolite-bands range in size from a few inches to many feet in length and breadth. Predominantly, the larger masses are lenticular, or have a length much greater than their breadth, although masses can be met with of quite varied shape.

As noted above, the elongate character of the bands is such that the longer axes of these are coincident with the foliation of the acid gneisses, and the few exceptions are indicative of a disruption of a band accompanied by separation of the constituent parts.

In many cases the gneissic foliation has flowed around the bands, being deflected from its prevailing direction at the extremities of the ribbon-like bands, and in other cases, the thermal effect of the enclosing gneiss has rendered the mass sufficiently plastic to conform to the intricate flow-movements in the gneiss itself. Beautiful examples of this structure can be seen on the wave-swept platforms on the coast of the hundred of Lincoln, and it is perhaps best exemplified on the eastern shores of the Point Boston promontory

(see fig. 2). The intricate foliation of the acid gneiss is faithfully followed by the plastic amphibolite. This structure is not to be interpreted as a case of the intrusion of a heterogeneous magma, in which the basic band represents a liquid layer conforming to the intricate foliation. The significance of this point will be dealt with in the discussion of the origin of the amphibolites.

Fig. 2.—*Thermally-metamorphosed basic inclusion, drawn out into a ribbon-like band, and contorted with the flowing movement in the magma, Point Boston.*



The disruption of the amphibolites into numerous smaller inclusions can be adequately traced on the rock-surfaces exposed to view along the coastline between low- and high-water mark. The masses are broken up by veins of the gneiss, and the remains of an amphibolite inclusion may be traced in the small angular fragments separated by veinlets of the enclosing gneiss (fig. 3, p. 83). Where foliation of the amphibolite-band has been pronounced, the influence of the invading solutions has been such that an intimate

penetration in lit-par-lit fashion has resulted, the foliation-planes being planes of maximum invasion. In many cases, this intimate penetration parallel to a pre-existing foliation has converted the foliated amphibolite into a hornblende-gneiss of hybrid origin.

Fig. 3.—*Disruption of an elongated amphibolite-inclusion (4 feet long) by movement in the flowing magmas.*

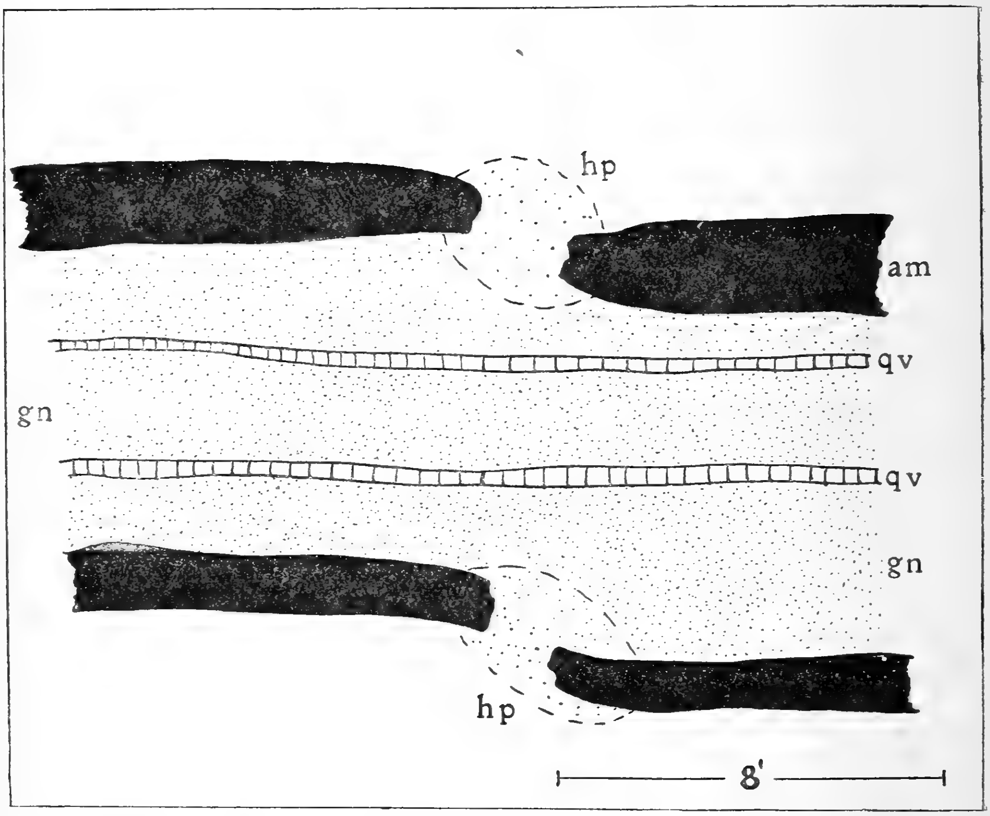
In other cases, the lit-par-lit intrusion is limited to the border of the amphibolite, while the central and often less markedly-foliated area is free from any injected material. By the flowing movements of the acid gneiss, many of the more rigid amphibolite-inclusions have been broken apart, the gneiss flowing in to fill the intervening space. This gneiss is usually of a coarse and pegmatitic type, and is often a true hornblende-pegmatite which passes by an imperceptible gradation into the normal granite-gneiss (see fig. 4, p. 84).

This structure is particularly well seen in the gneisses of the coast of Sleaford. The amphibolites of this region show, perhaps more characteristically than elsewhere, the complete enclosure of the amphibolites by an aureole of pegmatitic coarse gneiss or hornblende-pegmatite, which has no definite junction with the normal gneiss, but passes imperceptibly into it.

The amphibolite or hornblende-schist inclusions are often so abundant, that a survey of a clean platform of the gneiss shows bands of grey gneiss alternating with dark amphibolite-bands, and the appearance on the wave-swept shore-line of the southern coast of Sleaford is remarkably conspicuous. These bands of amphibolite are often of great length, measured in hundreds of feet, and their breadth is variable.

The pyroxene-bearing types behave similarly, and in the field it is impossible to differentiate them satisfactorily. The field name 'amphibolite' is utilized to include these types.

Fig. 4.—*Disrupted bands of amphibolite in the granite-gneiss of Sleaford Bay, with development of coarse pegmatite between the separated fragments.*



[gn=gneiss; am=amphibolite; hp=hornblende-pegmatite; qv=quartz-vein.]

Enough has now been said to show that these dark bands represent masses of anterior origin, which have been engulfed and oriented within the flowing gneiss. The petrography and origin of these rocks will be dealt with on a later page.

V. The Petrography of the Granites and Granite-Gneisses of the Flinders Series.

The granites and granite-gneisses of the Flinders Series are coarse-grained rocks in which the dominant ferromagnesian constituents are hornblende or biotite, or both. Although pyroxene is certainly a constituent of some of the gneissic types, it is more abundant in the massive varieties. In hand-specimens the rock

may appear massive, and the foliated structure is only brought out when a considerable area of the rock is viewed in the field.

There are certain types which characterize different areas: for example, garnet enters as an important constituent into the gneisses of the hundred of Sleaford, west of the Hutchison Series, and has not been observed in the gneisses of the Lincoln area; and there are other features which justify the division into two groups for descriptive purposes. But the appearance of garnet in the Sleaford rocks cannot be considered as implying any important distinction with regard to the origin of the rock-types.

I shall, therefore, describe the Flinders gneisses under

(*a*) The gneisses of the Lincoln area, to include the gneisses found east of the Hutchison Series; and

(*b*) The gneisses of the Sleaford area, to include types developed in the hundred of Sleaford as far west as the Red Banks on the western shore of this hundred.

(*a*) Gneisses of the Lincoln Area (Lincoln Gneisses).

The most characteristic rock of the Lincoln area is a coarse-grained augen-gneiss, which is developed in the type-section of Kirton Point, near the jetty of Port Lincoln.

The typical rock shows augen of felspar, or of felspar and quartz, usually aggregates and not single crystals, measuring up to an inch in length. The dominant ferromagnesian mineral seen in hand-specimens is a flaky biotite, but hornblende may also be discerned. The foliation is in a north-and-south direction, with a vertical dip.

Under the microscope the rock is seen to consist of quartz, plagioclase, microcline, biotite, hornblende, apatite, sphene, and magnetite. The quartz shows undulose extinction, and is sometimes singularly free from solid inclusions. There are the characteristic developments of pores along cracks of secondary origin. The plagioclase is developed with both albite and pericline twin-lamellation, and the properties are those of an andesine. Zonary banding is rarely seen. The andesine is characterized by rodlike inclusions oriented along definite crystallographic directions. Some of these have a platy habit, and are brownish, and of high refractive index, corresponding to rutile. In some examples these inclusions may also be present, but less characteristically in the quartz-grains. The potash-felspar shows considerable variation in the different types, but is usually a microcline often exhibiting a microperthitic intergrowth of albite. Myrmekitic intergrowths of quartz and plagioclase are often well developed, and typically in association with embayed grains of orthoclase.

Biotite is usually the most abundant ferromagnesian mineral. The pleochroic scheme for this mica is

$$X = \text{straw-yellow}; \; Y = Z = \text{dark brown.}$$

The included minerals are idiomorphic prisms of apatite, a few grains of sphene, and minute zircons with pleochroic halos.

The hornblende is associated with biotite. It is subidiomorphic, optically negative, $Z \wedge c = 16°$, and shows well-developed amphibolic cleavages. The cross-sections indicate that the forms (110) and (010) characterize the prism zone. The pleochroic scheme is

X = pale greenish-yellow ; Y = brownish-green ; Z = deep green.

These Lincoln gneisses (as already noticed) are by no means uniform in chemical or structural composition. While potassic microcline is usually the dominant felspar, various gradations are met with, and the plagioclase member may exceed the felspar in amount.

Under the microscope the gneissic structure is indicated by the parallelism of the elongate minerals biotite and hornblende, and this structure may be developed even when the rock-mass in the field shows but little evidence of flow-structure. On the other hand, types are met with which show no microscopical flow-arrangement of the minerals, the structure being typically granitic. Of the accessory minerals other than those already enumerated, pyrites and magnetite are the commonest, but occasionally an almost isotropic allanite is met with.

A microcline twinning is not a constant feature of the potash-felspars, and in these cases an orthoclase is defined. A perthitic character is common, and this (associated with the quadrille structure) yields the typical microcline-microperthite. This microperthitic structure is developed in two ways: (1) on a minute scale, in which very fine lamellæ of albite participate, and (2) in the presence of spindle-shaped grains of greater dimensions. The finer lamellæ are arranged with respect to a cleavage-surface (001) at an angle of 72°, as seen in sections parallel to (010), and, as W. C. Brögger has shown, are parallel to the steep orthodome ($\bar{8}01$). The spindle-shaped grains also are arranged parallel to this surface; but this development is less constant, and in some cases their longer axes subtend the (001) cleavage, an angle more acute of 63° or 64° corresponding to a linear arrangement parallel to the vertical axis. Two such arrangements of perthitic inclusions have been noted by Hennig, Suess,[1] and others.

The plagioclase of the Lincoln gneisses shows a composition varying from oligoclase-andesine to andesine, compositions more acid than this being rarely met with.

Hordes of fine acicular to platy inclusions are often a characteristic of the plagioclase. The edges of these needles are arranged along definite crystallographic directions. The edge of one set is developed parallel to the 'a' axis of the plagioclase, with two other sets running obliquely thereto.

As to the nature of these fine inclusions, it does not appear possible always to differentiate rutile from ilmenite-rods, for the latter mineral becomes translucent in very thin films. There is no development of the knee-shaped twins so characteristic of the

[1] F. E. Suess, Jahrb. K. K. Geol. Reichsanst. vol. liv (1904) p. 417.

former mineral. These inclusions present some of the features of the hæmatite lamellæ in the aventurine-felspars described by O. Andersen.[1]

A distinct type of inclusion is afforded by the presence of a more or less regularly oriented system of orthoclase-lenticles in some of the plagioclase crystals, corresponding to the 'antiperthite' of F. E. Suess.[2] These are usually developed parallel to the vertical axis, and would appear to correspond to the spindle-shaped grains of albite in microcline; they are assignable to an unmixing from a homogeneous solid solution consequent on cooling.

The peculiar quartz-plagioclase intergrowths which have been variously designated as 'quartz vermiculé' by F. Fouqué & A. Michel-Lévy,[3] and later by Dr. J. J. Sederholm[4] as 'myrmekite,' are a constant feature of the Flinders Series as a whole. The properties and nature of this myrmekite correspond very closely to the detailed description given by Dr. F. Becke.[5] In particular we may consider its distribution with regard to the microcline-felspar. The intergrowth is developed at the junction of the plagioclase with the potash-felspar, and without exception presents a convex surface to the microcline mineral, the wormlike quartz being usually roughly arranged perpendicularly to this surface. This convex and invasive character of the myrmekite into the microcline is strong evidence that the potash mineral has been replaced. The plagioclase of the myrmekite ground is in optical continuity with the plagioclase core. Becke has quantitatively measured the ratio of quartz to plagioclase, and finds that this index increases with the anorthite content of the felspar; in accordance with this evidence, he suggests that the changes involved may be represented by the equations

$$KAlSi_3O_8 + Na = NaAlSi_3O_8 + K,$$

$$2KAlSi_3O_8 + Ca = CaAl_2Si_2O_8 + 2K + 4SiO_2.$$

In treating of the origin and time of development of myrmekite Dr. F. Becke,[6] in a later paper, says:

> 'Gesteine mit ganz reinen Erstarrungsstrukturen scheint er zu meiden .... Ich kann angeben, dass ich ihn in Schliffen von Granit von Predazzo vergeblich gesucht habe. Auch in Schliffen des Granits vom Brocken habe ich ihn nicht finden können. Die Myrmekitbildung ist wohl auf Tiefengesteine und krystallinische Schiefer beschränkt.... Wenn man aus diesen Tatsachen einen Schluss ziehen dürfte, so ist es der, dass die Myrmekitbildung sich in einer Phase der Gesteinsbildung zu vollziehen scheint, die sich unmittelbar an die Erstarrung anschliesst, also zu einer Zeit, wenn die Temperatur noch der Erstarrungstemperatur nahe steht und noch Lösungsmittel im Gestein vorhanden sind.'

The comparative rarity of this intergrowth in the later Pre-Cambrian and Palæozoic granites, when its common occurrence in

[1] Amer. Journ. Sci. ser. 4, vol. xl (1915) pp. 351–98.
[2] Jahrb. K. K. Geol. Reichsanst. vol. liv (1904) p. 417.
[3] 'Minéralogie Micrographique' 1879, p. 193.
[4] Bull. Comm. Geol. Finl. No. 6, 1899.
[5] Min. Petr. Mitth. vol. xxvii (1908) pp. 377–90.
[6] Denkschr. K. Akad. Wissensch. Wien, vol. lxxv (1913) pp. 134–40.

the Archæan intrusives is considered, is a point of some significance.[1] It may well be that the Archæan granites were intruded at greater depths below the surface, or at least intruded into areas of higher regional temperature with less steep temperature-gradients, so that in the final stages of crystallization the residual solutions were able to act for much longer periods on the already crystallized minerals. The abundant presence of the high-pressure mineral, garnet, in many of these older Archæan intrusives is in agreement with this view. Myrmekitization is thus in part an albitization.

On the other hand, there is conclusive proof that some myrmekite may be of metamorphic origin. Dr. J. J. Sederholm[2] has noted the secondary development of myrmekite in granite which has been subject to strong mechanical metamorphism, with the development of mortar-structure. Here the myrmekite has formed along the zones of trituration, and can only be interpreted as posterior to this 'mortarization.' The same features may also be observed in the Lincoln area, where a fine secondary myrmekite has arisen in a similar fashion. The conditions prevailing at the conclusion of this 'mortarization' may well be not very different from those prevailing at the latest stages of consolidation (see p. 98).

In certain of the gneisses of Boston Island and the southern coast of the hundred of Flinders, a pyroxene takes the place of hornblende or biotite, and sometimes to their complete exclusion. This mineral is either a pale-green non-pleochroic diopside with diallagic lamination, or more commonly a pleochroic hypersthene, the rock then conforming to the original charnockite type.

The later differentiation-products of the gneisses consist of a series of hornblende-pegmatites and aplites.

The aplites generally form dyke-like masses cutting across the foliation, utilizing in this case the cross-jointing surfaces. Some of the hornblende-pegmatites have a similar habit, but many are in reality segregation-pegmatites. I have already noted the distribution of these pegmatites with reference to the amphibolite inclusions. They form a border-zone or halo to the amphibolites, and fill in the spaces between the separated portions of one amphibolite lenticle. It is clear that in some cases the amphibolite has yielded hornblende to the invading solutions. These hornblende-pegmatites pass by an imperceptible gradation of texture into the normal granite-gneisses.

The constitution of the pegmatites is very similar to that of the gneisses, both microcline and plagioclase (oligoclase-andesine or andesine) being found. Some of this andesine shows acicular inclusions similar to those observed in the felspar of the main granite-mass. Biotite is a rare constituent of most of these pegmatites. The hornblende is a black prismatic type, with well-developed idiomorphic outline, attaining as much as 1½ inches

[1] Myrmekite is present, however, in some of the Caledonian intrusions of Scotland: for example, in the granites of Galloway.

[2] Bull. Comm. Geol. Finl. No. 48 (1916) pp. 127–29.

in length. A green diopsidic pyroxene of high extinction-angle may sometimes form an important constituent of these hornblende-pegmatites.

The aplites are fine pink-weathering rocks, consisting of quartz and microcline or an acid plagioclase. A prominent aplite near the Kirton-Point jetty is an interesting type in which the dominant felspar is albite, although microcline is also present. The rock has been veined by epidote-strings, and the albite is filled with little crystals of an epidote of the clinozoisite type. These grains show a noteworthy variation of interference-colour within the same crystal, and the presence of parallel growths of epidote and clinozoisite is indicated. The albite shows no development of the chequer-structure (schachbrett-albit), which is a common feature of the albitites and soda-aplites of South Australia.[1]

(b) Gneisses of the Sleaford Area (Sleaford Gneisses).

The principal distinguishing feature of the Sleaford gneisses is the presence of garnet, which is widely developed throughout the accessible exposures of these rocks in the hundred of Sleaford. The prevailing rock-type is a garnet-biotite-gneiss, consisting of quartz, microcline, plagioclase of the composition of oligoclase-andesine or andesine, biotite, garnet, and the accessories apatite, magnetite, and zircon. Myrmekite is as frequent a constituent of these rocks as of the Lincoln Series, and shows the same relations to the adjacent minerals.

Types containing a member of the pyroxene group of minerals are also more frequently met with than in the Port Lincoln district. We thus find garnet-hypersthene-gneisses, as well as diopside varieties. Hornblende is also a common mineral, but is not so abundantly developed in the granite-gneisses as in the area already described.

The garnet is a pink almandine, occasionally reaching half an inch in diameter, but commonly much less. Under the microscope it is colourless to pink, and invariably isotropic, as is usually the case with pyrogenetic garnets.

In a number of the pyroxene-bearing types of gneisses, the garnet may form a corona round other minerals, being developed in this manner around such minerals as magnetite, hornblende, or pyroxene. In some of these examples there is sufficient evidence, if such were necessary, that this is a primary corona structure, its relation to the associated minerals enforcing this conclusion on chemical grounds.

In addition to the minerals already mentioned, sphene and a mineral agreeing most closely with allanite are occasionally found.

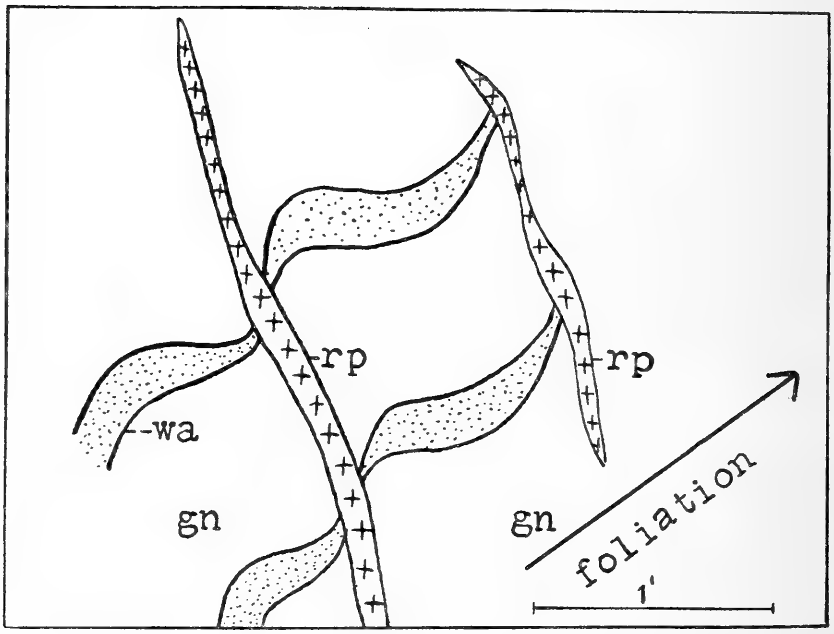
The most abundant type of pegmatite in this region is a

[1] C. E. Tilley, Trans. Roy. Soc. S. Austr. vol. xliii (1919) pp. 316–41; also W. R. Browne, *ibid.* vol. xliv (1920) pp. 1–57.

coarse hornblendic variety. The amphibole occurs here in crystals exceeding in size those found elsewhere in the Flinders Series. Quite commonly, crystals 3 inches long are present, and in one case a single crystal, 8 inches long and $1\frac{1}{2}$ inches in diameter, was noted. The relations of these pegmatites to the basic amphibolite inclusions are similar to those already described for the Lincoln area.

Pegmatites carrying large crystals of pink garnet are also not uncommon, the felspathic constituents being both microcline and acid plagioclase, the former predominating. These often show a distinct gneissic banding, and with a finer granulation they pass into aplite-gneisses.

Fig. 5.—*Banded gneiss, Red Banks.*



[wa=aplitic gneiss; gn=grey gneiss; rp=red pegmatite.]

The granites which form sill-like masses in the metamorphosed sediments of Sleaford Bay are hornblendic types, and do not carry garnet. Their felspars are again microcline and plagioclase, the latter being usually more acid in composition than the plagioclase of the main granite-gneisses of this region. The composition of their plagioclase is, however, never more acid than that characteristic of an oligoclase-albite.

The foliation of the Sleaford gneisses presents the same features as those expressed in the gneisses of the Lincoln area, but they are here developed on a more extended scale, with additional peculiarities. This foliation has a general southward direction, with the planes steeply inclined. The additional feature to be remarked is the frequent presence of a marked banding. The

best exposures of these banded gneisses are seen at the headland north of Fishery Bay, and again on the coast near the Red Banks, Western Sleaford. At the latter locality, the gneiss shows bands of differing composition: dark bands containing larger percentages of ferromagnesian minerals are seen to alternate with white aplitic or quartzose bands, the whole being closely contorted. These are crossed, perpendicularly to the banding, by reddish pegmatite-veins. In some cases the white aplitic bands are drawn out into lenticles, and at the points of attenuation the red pegmatite-veins have been intruded transversely (see fig. 5, p. 90).

Xenoliths of Sedimentary Origin in the Sleaford Gneisses.

Fragments of the Hutchison Series engulfed in the Flinders Series of gneisses are to be found sparingly developed at various points in the Sleaford area. The most notable locality is the headland north of Fishery Bay. From this locality, diopside-rocks have already been described in an earlier paper. There are, however, certain additional xenoliths closely associated with these which have not as yet been described. These xenoliths are represented by knots and bands in the gneisses, the knots reaching a diameter of as much as 5 inches. They are very rich in garnet, and on account of their more resistant weathering project from an otherwise fairly smooth face.

As seen under the microscope they consist of pink garnet, green spinel, biotite, magnetite, and pyrites. Garnet is the most abundant constituent, but is intimately intergrown with the spinel. This mineral is dark green, forming rounded intergrowths, and often enclosing magnetite-granules. The line of demarcation between the magnetite and the spinel is sharp, and without any gradation of colour to suggest the presence of any extended mutual solubility of the group $FeO.Fe_2O_3 \ldots FeO.Al_2O_3$. The spinel is a member of the pleonaste-hercynite group (see fig. 6, p. 92).

The biotite occurs in well-developed flakes, showing a pale-yellow to reddish-brown dichroism. There are no pleochroic haloes in the biotite where the spinel is enclosed in this mineral. There are, however, sometimes present minute pleochroic haloes around zircon enclosures. Some intergrown plagioclase of andesinic composition is present.

In the gneiss associated with these knots are sometimes found individual crystals of garnet, containing intergrowths of green spinel, and in addition sillimanite may be similarly present (see fig. 7, p. 92). These are fragments of an original xenolith, which has become disintegrated by the fluid magma.

There are narrow schistose bands in this locality, consisting of biotite and garnet with subordinate potash-felspar. The garnet in these bands shows an anomalous anisotropism.

The presence of such highly-aluminous minerals as spinel and

Fig. 6.—*A garnet-spinel xenolith enclosed in the gneisses of Sleaford.* × 27.

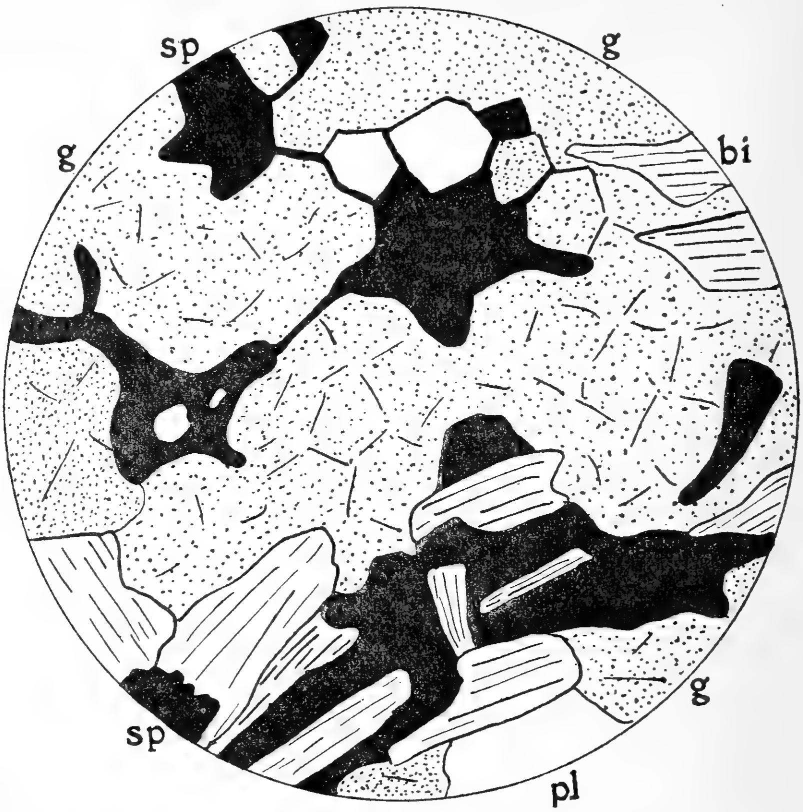
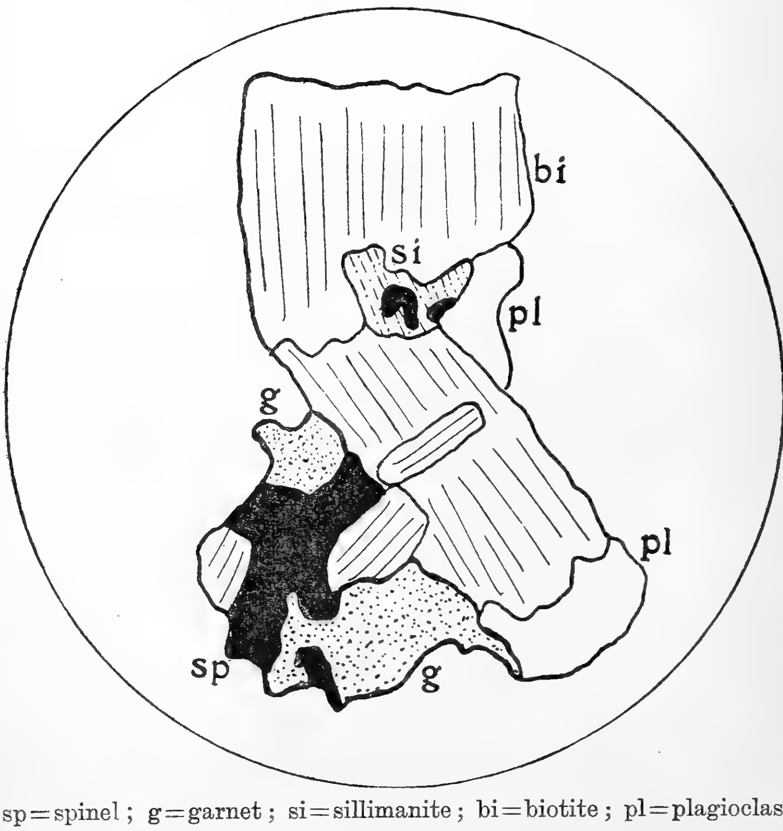


Fig. 7.—*Xenocrysts of spinel, sillimanite, and garnet in the Flinders gneisses.* × 30.



[sp=spinel; g=garnet; si=sillimanite; bi=biotite; pl=plagioclase.]

sillimanite, in addition to that of recognizable xenoliths of sedimentary origin, confirms the view that these knots and bands are xenoliths of the accidental kind. In these cases the garnet of the knots themselves, and some of the garnet-grains of the enclosing gneisses, are also to be considered xenolithic, for spinel and sillimanite are developed within their borders.

A source for these xenoliths can be readily found in the para-garnet-gneisses of the Hutchison Series, which, in common with the diopside-rocks, form the shores of Sleaford Bay.

In an earlier paper[1] I described garnet-gneisses from the Hutchison Series at this locality, and northwards in the hundred of Hutchison, containing garnet, spinel, and sillimanite. The mutual associations of these minerals (spinel and sillimanite enclosed in garnet) in the knots of the Sleaford gneisses can be matched in the paragneisses of the Hutchison Series.

It may be concluded, therefore, that, like the diopside-xenoliths at Fishery Bay, these garnet-spinel knots are fragments of the older Hutchison Series metamorphosed and incorporated in the fluid magma. It will be observed that such aggregates were met with only in this locality, and I cannot subscribe to the view that the normal garnet of the garnet-gneisses is a product of absorption of aluminous sediment by the magma. This point is dealt with on a later page (see p. 94).

A point of interest to be further noticed regarding spinel in these aggregates is, that it is never seen in contact with quartz, although it abuts against plagioclase. Whether on spinel of hercynitic type becoming enclosed in contact with free silica of the magma, there results the formation of cordierite, or of garnet and sillimanite, has been already discussed in the paper just cited,[2] and calls for no further remark here.

The occurrence of garnet and pyroxene (both diopside and hypersthene), which, in addition to the dominant biotite and hornblende, are important constituents of the gneissic rocks, calls for some remark. Dealing first with garnet, we may note that Dr. A. Osann[3] concludes that its presence in granites indicates an abnormal content of alumina in the magma, and suggests that it is derived by absorption of sediment. To this view, from a study of the Archæan granites of Finland, both Dr. J. J. Sederholm[4] and Dr. P. Eskola[5] have subscribed. The application of this principle on a general scale to account for the uniform appearance of garnet in great granitic tracts is, however, a doubtful procedure, and the presence of that mineral is probably explicable on other grounds. There seems to be little reason to doubt that garnet can appear as a normal pyrogenetic mineral, and the probability that it

[1] Geol. Mag. 1921, pp. 251-59.

[2] *Ibid.* pp. 305 *et seqq.*

[3] 'Petrochemische Untersuchungen' Abhandl. Heidelb. Akad. Wissensch. No. 2, pt. i (1913) p. 21.

[4] Fennia, vol. viii (1892) No. 3, p. 20.

[5] Bull. Comm. Geol. Finl. No. 40 (1914) pp. 30-31.

represents a rearrangement of the biotite-molecule must be considered.

In the following equation

$$(1)\ H_4K_2Mg_2Fe_4Al_6(SiO_4)_9 + 3SiO_2 \rightleftarrows 2KAlSi_3O_8 + 2Fe_2MgAl_2(SiO_4)_3 + 2H_2O$$

the formation of garnet and orthoclase is represented as the product of a reversible reaction, of which quartz and biotite are the interacting members. Now, this reaction is an important one that is revealed in metamorphism. Under a high-grade metamorphism, as has been shown elsewhere, garnet and orthoclase are prominent constituents of the paragneisses of Sleaford Bay, and the reversibility of the above equation is confirmed by the visible mineral associations which these rocks reveal, where, owing to the limited amplitude of diffusion, the equation is susceptible of confirmation. Under diminishing pressures and lower temperatures, the reaction proceeds in the reverse direction.

It is probable that this equation, or one in all essentials identical therewith, may represent one of the equilibria tending towards establishment in the liquid magma. Garnet is characteristically a high-pressure mineral, and the formation of the garnet-molecule in the magma may be a function of the pressure. This reversible equation might, therefore, not be established in magmas subject to normal pressures during intrusion, to any degree. With higher pressures and a consequent shift of the equilibrium strongly from left to right, and under these conditions favouring the formation of the garnet-molecule, its precipitation is arrived at with saturation, and the removal of solid garnet from the solution involves the reaction proceeding continuously to the right either until one of the constituents is exhausted, or until some change of condition disturbs the equilibrium.

The presence of much volatile mineralizer as water, as N. L. Bowen[1] has indicated, probably involves a splitting-up of the polysilicate molecule of orthoclase, a reaction analogous to hydrolysis, into the orthosilicate molecule and silica, the orthosilicate molecule representing a constituent of the biotite molecule

$$(2)\ KAlSi_3O_8 \rightleftarrows KAlSiO_4 + 2SiO_2.$$

Inspection of equation (1) shows that a comparative deficiency of water-vapour favours the reaction proceeding from left to right, and this is probably a further factor to be considered, as noted below.

The presence of diopside and hypersthene as constituents of acid granites is sufficiently familiar in the well-known charnockite type, and their presence in the members of the Flinders Series present no extraordinary points of interest. It has been remarked that the existence of pyroxenes in rocks so far differentiated as acid granites implies a relative deficiency of volatile mineralizers,

[1] Journ. Geol. Chicago, vol. xxiii (1915) Supplem. pp. 44–45.

water in particular, in comparison with biotite-granites: the function of water in the case in question involving a degradation of poly- and metasilicate molecules, for a high content of water favours not only the orthoclase degradation, but that of the metasilicates of lime and the ferromagnesian elements. The presence of hypersthene, diopside (the latter both in the granites and pegmatites), and perhaps even hornblende itself (but to a much less degree), is strongly suggestive of a relative water deficiency in the crystallizing magma. Thus the equation

$$(3)\ K_2(FeMg)_2Al_2Si_3O_{12}+5SiO_2 \rightleftarrows 2(MgFe)SiO_3+2KAlSi_3O_8$$

might be represented as a reversible equilibrium in the magma, the reaction proceeding to the left in the presence of abundant water, and, with a deficiency, to the right, resulting (in the latter case) in a saturation of the magma with the metasilicate molecule, and its consequent crystallization: or the equation representing the association of hypersthene and garnet, a not uncommon occurrence in the Sleaford gneisses, as of the type

$$(4)\ 2H_3K_3Mg_2Fe_4Al_6(SiO_4)_9+12SiO_2 \rightleftarrows 6KAlSi_3O_8+3Fe_2MgAl_2(SiO_4)_3$$
$$+Fe_2Mg(SiO_3)_3+3H_2O.$$

The conditions favouring the right-hand side of the equation are, as before, high pressure and a relative deficiency of volatile water.

The gneissic foliation and banding of these gneisses of the Flinders Series presents a problem which has arisen in the investigation of most Archæan areas of the world, and it has long been recognized that gneissic foliation may arise in various ways. When we deal with the structures revealed in the Flinders gneisses of Southern Eyre Peninsula, the conclusion is enforced that the features exposed in this tract can only be ascribed to conditions obtaining during the primary consolidation of these rocks, in contrast with any foliated structure arising through metamorphic influences, subsequent to the consolidation of the rocks themselves. Even so, however, there are various ways in which a gneissic foliation may be impressed during the crystallization period, and representatives of these different modes of origin are to be recognized within the group in question.

It is obvious that the first requisite for the setting-up of a gneissic foliation or banding in a fluid magma is a magmatic heterogeneity. Heterogeneity in a magma can arise:

(*a*) by differentiation in which a fluid magma contains solid crystals of earlier-formed minerals, which have not settled by gravitative processes; or

(*b*) by the presence of foreign material within the magma.

Under (*b*) the only case that calls for consideration in the Flinders Series is the presence of inclusions of earlier-formed rocks, as the widespread amphibolites and hornblende-schists.

The second requisite is deformation, or a shearing movement giving rise to flow of the magma.

These essentials being granted, it is possible to account reasonably for the features presented by the gneisses of the Flinders Series. Let us take first the case of a heterogeneous magma arising from differentiation, and we shall note that under this head come those gneisses which show evidences of a flow-structure as distinct from a gneissic banding. The elongate minerals, such as biotite and hornblende, are the principal determining features of this foliation. Flow-movements arising during the crystallization of these minerals, when the quartz and felspars were largely in solution in the magma, are responsible for the orientation and alignment of these minerals.

In considering the explanation of the origin of banded gneisses an additional feature is to be remarked. Examined under the microscope, the banded gneisses show an alternation of dark bands richer in the earlier-formed minerals, with bands principally composed of quartz, or quartz and felspar.

In all cases it is evident that quartzose, or quartzo-felspathic bands have crystallized later than the darker bands, the relations in some cases being visibly intrusive. It seems clear that we have here a magma in which crystallization has progressed far. The magma may be pictured rather as a crystalline meshwork, in which the interstices are filled with the quartzose or quartzo-felspathic solutions. It is not difficult to conceive of a meshwork of this description in which the crystalline mass is penetrated by interstices carrying the residual fluid in continuous contact, much as in a sponge, and a mass very susceptible to shearing. A consideration of the influence of shearing movement on such a crystalline meshwork indicates that a prime factor is the mobility of the interstitial liquid. Under deformative movement, cavities may be produced, which on account of that same mobility are immediately filled with liquid from the neighbouring interstices of the mesh. Such cavities would possess in general a lenticular shape, corresponding to the direction of the impressed force. Continued action of this kind, under a constant shear-direction, and moderate temperature-gradient, would finally result in the production of a banded structure of definite orientation, and of such a mineral composition of alternating bands (which is in accordance with the progressive crystallization, the bands bearing very similar mutual relations) as that which obtained between the original crystallized minerals and the liquid at the initiation of this process.

It is to be remarked that not only is a parallel alignment of the banding thus established, but that the elongate minerals of the bands adjust themselves to this orientation, and thus we may see where individual crystals of the mesh become involved in the liquid residuum. There is, consequently, foliation superposed on a more or less unidirectional banding. The processes at work in this shearing are clearly unfavourable to any gravitative separation of crystals.

It may further be suggested that if, when an approximately parallel banding is established, and before consolidation has

advanced too far, the direction of shear is for any reason locally deflected, contortion and buckling of the bands themselves—and more particularly of those later quartzose and quartzo-felspathic bands—would ensue. With a more pronounced deflexion of the shear-direction at the latest stages of consolidation, the final residuum of liquid might be expected to crystallize in narrow and interrupted lenticles aligned with the new direction of shear.

There remains for discussion the third type, in which heterogeneity has arisen by the presence of foreign enclosures. The best examples of gneissic banding arising in this way are the classic Tertiary gneisses of the island of Rum, as described by Dr. A. Harker.[1]

In the gneisses of the Flinders Series, the development of gneissic foliation or banding from the presence of enclosures is not on any extensive scale, but it may become locally important. The foreign enclosures in this case are pre-existing amphibolites or hornblende-schists. In the first place, it will be noted that those amphibolite-bands which assume an elongate habit are (with few exceptions) oriented with their longer axes parallel to the flow-movements in the liquid magma. It will be further observed that many of these inclusions are themselves foliated, and in general parallel to their longer axes. During incorporation by the fluid magma, they have been injected along their foliation-planes by the more fluid portions, and this injection has occasionally been so intimate as to convert the foliated basic rock into an injection hornblende-gneiss. Where such masses of amphibolite have been torn off or separated from the main body of the amphibolite, the resulting hornblende-gneiss of hybrid origin may be indistinguishable from the main body of the normal gneiss; but the process can be traced in its entirety around large masses of engulfed amphibolites.[2]

With regard to features of metamorphic origin in the Flinders gneisses, these cannot be regarded as developed on any great scale. The metamorphism following the consolidation of the gneisses is of a comparatively low-grade mechanical type. This finds expression in the development of marked strain-shadows in the quartzes and felspars, the undulose extinction in extreme cases being accompanied by a mechanical mortar-structure. Even these features appear to be localized rather than uniformly spread, and are recognized from particular areas or belts which have succumbed to the effects of stresses.

An interesting feature is occasionally developed where mortar-structure is dominant, in the presence of a fine myrmekite, which

[1] Q. J. G. S. vol. lix (1903) pp. 207–15.

[2] The subject of primary gneissic banding has been discussed by N. L. Bowen and F. F. Grout, with special reference to the Duluth Lopolith, in recent volumes of the Journal of Geology: Bowen, vol. xxvii (1919) pp. 411–26; Grout, vol. xxviii (1920) pp. 255–64; Bowen, *ibid.* pp. 265–66.

cannot be regarded as antecedent to the crushing; but it is certainly produced in the period immediately following mechanical movement, this movement affording channels for the circulation of solutions, possibly at a locally slightly-elevated temperature developed frictionally. This myrmekite is thus of purely metamorphic origin.

VI. The Petrography of the Amphibolites and Allied Types in the Flinders Series.

(*a*) The Amphibolites and Hornblende-Schists.

The dark basic bands of the Flinders gneisses can be separated into two divisions, these divisions depending on the nature of the dominant ferromagnesian mineral. Those bands which are defined as amphibolites contain hornblende as the predominant ferromagnesian mineral, although it may be accompanied by pyroxene, of diopsidic constitution, and occasionally by garnet. In the second division, the dark hue of the rock is usually less pronounced, and pyroxenes form the dominant magnesian minerals. Usually both rhombic and monoclinic pyroxenes are present, and hornblende may appear.

If we turn now to the rocks of the first class, the amphibolites may best be described as dark basic masses bearing the stamp of metamorphosed rocks, the essential constituents of which are plagioclase and hornblende. The nature of the amphibolites can be sufficiently indicated by a description of one type, and a detailed account will therefore be given of an amphibolite occurring on the shore at Kirton Point, Port Lincoln.

This amphibolite is intercalated in the gneisses as a long band, the orientation of which is dependent on the primary foliation of the orthogneisses—the longer axis of the inclusion being parallel to this foliation. It is a dark rock with glistening crystals of hornblende, and has itself a distinct foliated structure. Under the microscope the constituents seen to be present are hornblende, plagioclase, with accessory quartz, magnetite, apatite, and a few isolated grains of pyroxene. The foliated structure of the rock is apparent in thin section by the parallel orientation of the hornblende.

The hornblende is subidioblastic, with well-developed amphibolic cleavages, $Z \wedge c = 20°$. The pleochroism is

X=yellowish-green, Y=brownish-green, Z=green, and the intensity $Z \gtrsim Y > X$.

In the plagioclase, twinning after the albite, Carlsbad, and pericline laws can be observed, but the two last-mentioned laws are not characteristic for these grains. Some of the plagioclase is wholly untwinned. Sections perpendicular to (001, 010) give an extinction of 13°, thus corresponding to an andesine of composition Ab_2An_1. Most sections examined give positive birefringence, but a few indicate a negative character. The refractive index has nearly the same range as quartz. Grains showing negative optical character indicate a transition to oligoclase-andesine.

Quartz is quite xenoblastic, and is interstitial in its development. Small granules of magnetite are included in hornblende at the junctions of abutting amphibole-grains. Acicular crystals of apatite are present in the felspar. There is also a very small amount of low-refraction felspar present in strand-like threads between grains of plagioclase, and this has the properties of orthoclase. The few grains of pyroxene present associated with felspar have the properties of diopside. The hornblende here is not paramorphic after pyroxene, but has crystallized as such.

In another type at the same locality, the igneous origin of the rock is at once made apparent by the presence of blastophenocrysts of felspar in a hornblendic finely-granular ground-mass. In such types the blastophenocrysts of felspar have undergone considerable alteration, in which a sericitic mica (? paragonite) and zoisite are prime decomposition-products. The composition (where determinable) suggests andesine or labradorite.

The ground-mass felspar is usually less decomposed, and its composition varies from calcic andesine to a labradorite (Ab_1An_1). The hornblende is usually associated with a small amount of quartz, and the iron-ore is generally magnetite, although ilmenite is also recorded from some of these types.

A striking amphibolitic type is met with, intercalated in the Flinders gneiss, on the western shores of Sleaford Bay. This is a foliated rock of medium grain, containing lenticles or augen of felspar, sometimes with a little garnet, arranged with their longer axes parallel to the foliation. The whole structure is suggestive of lit-par-lit injection of an uniform amphibolite. Under the microscope the constituents are seen to be hornblende, plagioclase, pyroxene, and a little biotite.

A section through one of these eyes shows it to consist of plagioclase-grains. The texture is characteristically of the pflaster type. These grains prove to be labradorite, with a symmetrical extinction in the zone perpendicular to (001) of 33°. The plagioclase of the amphibolite proper is of approximately the same composition (30°).

Pyroxene and hornblende are intergrown. The former occurs as clear grains of diopside of pale greenish tint. The amphibole and pyroxene have evidently crystallized together.

The proneness of the felspars to decomposition in the amphibolites is especially noticeable in the blastophenocrysts of the blastoporphyritic varieties, and this decomposition is usually (as noted above) to a member of the zoisite group and a sericitic mica. The decomposition is doubtless expressed by the equation

$$NaAlSi_3O_8 + 4CaAl_2Si_2O_8 + 2\ HOH = H_2NaAl_3(SiO_4) + 2HCa_2Al_3Si_3O_{13} + 2SiO_2.$$

The accessories accompanying the hornblende and plagioclase in the amphibolites of the Flinders Series are usually magnetite, quartz, apatite, and (occasionally) zircon. Ilmenite has been but rarely observed, and sphene is conspicuous by its absence. Considering the widespread occurrence of titanite in normal amphibolites,

its rarity in the amphibolites under discussion is noteworthy, pointing to an original pyroxene, from which the hornblende is ultimately derived, of low titanium content. Quartz is usually present in small amount, and this is to be regarded as a normal feature of amphibolites which have been derived by metamorphism of basic igneous rocks. Biotite and pyrites are further accessories. A small amount of biotite developed in flakes in the amphibolite imparts to the rocks a distinctly foliated appearance.

Quartz and orthoclase are essential constituents of certain amphibolites, and these two minerals may in such cases be present in considerable amount. These constituents, therefore, mark off a dividing-line from the amphibolites which have already been discussed.

Quartz- and Orthoclase-bearing Amphibolites.

Amphibolites in which these minerals are conspicuous are not characterized by any definite texture. Some of them are comparatively coarse-grained, are foliated like hornblende-schists, and have been injected lit-par-lit fashion by the invading gneisses. There are others of quite massive appearance, and of very fine grain, not unlike that of a dense basalt.

These types are to be met with principally in the Lincoln area. A medium-grained inclusion at Kirton Point, showing veining and intrusion by the acid gneiss, consists of hornblende, plagioclase, orthoclase, quartz, biotite, apatite, and magnetite. While the predominant minerals are hornblende and plagioclase, yet the potash-felspar and quartz are not inconsiderable constituents. The orthoclase is readily picked out by its low refractive index and small extinction-angle. The quartz is usually distinguished from the plagioclase by its higher double refraction, and by absence of twinning, when this is a constant character of the plagioclase. A useful point of discrimination is the characteristic undulose extinction developed in bands in the quartz, which is seldom to be observed in the felspar. The amount of quartz in some of these types is clearly in excess of that postulated by any conversion of pyroxene to amphibole. The composition of the plagioclase in the rock under discussion points to andesine (Ab_3An_2), giving an extinction-angle of 20° in sections perpendicular to the crystallographic axis *a*. The apatite is present, both as fine acicular needles and as rounded grains of larger size.

As an example of a fine-grained amphibolite which is an orthoclase-bearing type, a band developed in the gneiss on the east side of Point Boston may be taken for description. This rock affords one of the best instances of the thermal effect of the engulfing gneiss on the amphibolites. The band has been rendered plastic by its incorporation, and drawn out to follow the intricacies of the flowing gneiss. It is a dark-grey rock, of dense structure, and has a specific gravity of 2·95. The constituents, as seen under the microscope, are plagioclase, hornblende, quartz, orthoclase, magnetite, apatite, and a trace of pyrites in cubes. A foliated appearance is given by the parallel orientation of the hornblende-prisms.

It is notable for its high content of magnetite, although this feature is not particularly manifest in the specific gravity, owing to the development of quartz and orthoclase in considerable amount. The plagioclase has the composition of a calcic andesine, and both felspars and quartz are crowded with fine needles of apatite. On account of its rather abnormal composition, this rock has been regarded as a critical one for analysis, which might be expected to throw further light on its genesis. The accompanying table embodies the analysis, with a number of other analyses appended for comparison.

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	55·23	56·20	56·17	56·78	57·21
Al_2O_3	13·02	15·46	13·62	14·33	12·99
Fe_2O_3	7·66	1·54	7·46	5·76	3·28
FeO	6·60	9·76	7·81	9·27	10·18
MgO	2·27	1·83	3·43	1·58	1·59
CaO	5·87	5·39	6·52	5·26	5·97
Na_2O	2·80	2·78	3·09	3·43	3·07
K_2O	2·93	2·56	0·83	1·75	1·61
H_2O-	0·15	0·16	1·09	0·33	0·68
H_2O+	0·50	0·59		0·10	1·63
P_2O_5	0·79	1·13	...	0·36	0·44
TiO_2	2·85	2·25	...	1·44	1·72
Accessories	...	0·37	...	0·25	0·43
Totals	100·67	100·02	100·02	100·64	100·80

I. Amphibolite. Point Boston, Eyre Peninsula (South Australia).

II. Quartz-gabbro. Cherokee County (Georgia). F. W. Clarke, Bull. U.S. Geol. Surv. 419 (1910) p. 38.

III. Amphibolite. Längenfeld, Ötzthal. F. Becke, Denkschr. K. Akad. Wissensch. Wien, vol. lxxv (1913) p. 184.

IV. Diabase. Somerset County (New Jersey). A. H. Phillips, Amer. Journ. Sci. ser. 4, vol. viii (1899) p. 279.

V. Diabase. Kittitas County (Washington). F. W. Clarke, Bull. U.S. Geol. Surv. 616 (1916) p. 461.

The rock is remarkable for its high content of iron oxides, and in particular that of ferric oxide. This finds its explanation in the abundant presence of magnetite.

A calculation of the norm shows that it consists of

Quartz	15·36
Orthoclase	17·23
Albite	23·58
Anorthite	14·45
Diopside	8·36
Hypersthene	2·92
Magnetite	11·13
Ilmenite	5·32
Apatite	1·55
	99·90

It bears perhaps most resemblance to the quartz-gabbro of Georgia, only differing notably from this in the content of ferric oxide. The iron content finds a parallel in the amphibolite recorded by Becke, Analysis III. The diabases of New Jersey and Washington also resemble it in ultimate composition, the former of these containing quartz as a modal constituent.

An instructive illustration of the mode of development of an orthoclase-bearing amphibolite is found in a prominent amphibolite-band included in the gneisses at Kirton Point. The band in question is strongly foliated at its border, and has been injected lit-par-lit fashion by the pegmatitic solutions. At its centre, however, it is free from any intrusive veins, and presents a much less foliated appearance.

A thin section of the border-rock near an invading pegmatite veinlet shows it to contain hornblende, plagioclase of andesinic composition, some orthoclase, and quartz evenly distributed. Apatite and magnetite form the accessories. This veinlet of pegmatite is one of the plagioclase types of hornblende-pegmatite. It is of interest to note that, while the plagioclase of the amphibolite is water-clear and undecomposed, the felspar of the vein is largely filled with sericitic products. This selective weathering of felspar of igneous origin as compared with metamorphic felspar is referred to elsewhere (p. 110).

When the central more massive portion of the band is examined microscopically, an entirely different textural composition is seen. It is in this central portion of the mass that a clue to the origin of the amphibolite is given. The texture and composition is that of an igneous rock. The constituent minerals are plagioclase, pyroxene, hornblende, magnetite, apatite, quartz, and orthoclase.

The plagioclase occurs in lath shape to prismatic form, and carries many fine dusty enclosures, most of which are zonally arranged. These felspars are the original unchanged crystals of the primary igneous rock. The pyroxenes include both an augite and the rhombic hypersthene, the latter in grains showing pink to green pleochroism. The augite is a grey greenish type, and is the dominant pyroxene. The hornblende is of the usual type, and has been derived from the pyroxenes, as this uralitization can be seen in progress.

The quartz and orthoclase form rude intergrowths on a minute scale of a somewhat granophyric type, between the remaining minerals. It is quite clear that these intergrowths were the last to consolidate, and the structure of certain granophyric quartz-dolerites is here recalled, or in particular the micropegmatite interstices of many dolerites.

This rock is therefore a definite igneous type, in which the uralitization of portion of the pyroxene is the main impress of metamorphism. When, however, the border of the same rock-mass is examined, it is seen that the metamorphism involved has been of a more fundamental type. There is now no pyroxene remaining,

the felspars have been recrystallized, and the micropegmatite is represented by the quartz and orthoclase-grains.

This border recrystallization, with a more or less unchanged core of igneous rock, is the result of the thermal metamorphism of the invading granites, and the nature of the original rock from which the amphibolite is derived supports the suggestion that has already been noted in the similarity of the analysed amphibolite to the quartz-gabbros and dolerites.

Some further remarks will be made in connexion with the origin of the amphibolites in general.

Garnet-Amphibolites.

Amphibolites containing garnet as a constituent have been met with as inclusions in the Sleaford gneisses, and a closely similar type is found at Kirton Point, Port Lincoln. The specimens here were obtained from a large block on the shore not *in situ*; but obviously the source is near at hand, although a search did not discover it. These garnet-amphibolites are foliated dark rocks in which there are conspicuous grains of red garnet.

Under the microscope the constituents are seen to be hornblende, garnet, pyroxene, plagioclase, quartz, and sphene. Accessorily present are magnetite and pyrites.

As the nuclei of numerous pleochroic haloes, minute inclusions of two types occur: one a colourless mineral of high refractive index, the other being grains of a yellowish strongly-refringent mineral, which is probably rutile. The colourless mineral is probably epidote; but its minute size prevents a definite determination. Numerous spindle-shaped grains of titanite associated with hornblende appear not to be radioactive, as they are never surrounded by pleochroic haloes. Hornblende is the most abundant mineral in the slides, and occurs in plates measuring up to ·75 mm. in length.

The pleochroic scheme is as follows :

X = yellow, Y = yellowish-green, Z = brownish-green.

Garnet porphyroblasts occur measuring in greatest diameter up to $1\frac{1}{2}$ mm. The shape is extremely irregular, but the crystals never show anomalous birefringence. They contain poikiloblastically grains of quartz and often grains of hornblende and plagioclase.

The irregular outline of the garnet and its much-fractured state are indicative of movement in the rock since the genesis of garnet. There is evidence here also of an initiation of degradation of the garnet yielding hornblende and plagioclase. The crystals are often surrounded by a thin ring of colourless material, of which a prominent constituent is plagioclase. This gives place externally to little crystals of hornblende. Again, the garnet may be surrounded by a quasi-diablastic intergrowth of hornblende and plagioclase, and this may develop in the form of bays into the original garnet-crystal.

Pyroxene is present only in small amount. It is occasionally seen to be undergoing uralitization: but in the majority of cases the hornblende is of entirely new crystallization. Moreover, pyroxene and amphibole may appear together with idioblastic outlines. The augite is slightly greenish, but is not sensibly pleochroic. This pyroxene cannot be the original pyroxene of the igneous rock from which the amphibolite is derived, but has itself been recrystallized. What are probably ilmenite-grains are sometimes developed as inclusions in the pyroxene, and are also to be seen as cores to spindle-shaped grains of titanite.

Plagioclase with quartz forms the interstitial material.

The felspar occurs in irregular to rounded grains showing albite-lamellation, and occasionally pericline in addition. The inverse zoning characteristic of metamorphic plagioclases has also been recorded, but a zonary structure is not a constant feature.

Optically the plagioclase has the properties of oligoclase-andesine and andesine. The sign of the birefringence is for the most part negative, but positive grains have been recognized. Sections perpendicular to (010) show symmetrical extinction up to 16°.

Quartz which is intimately associated with plagioclase is to be considered as the normal bye-product of the amphibole development. In a further varietal type, pyroxene has completely disappeared, and biotite and apatite are further accessories.

The low-temperature degradation of garnet here has yielded chlorite, showing the anomalous interference-tints of penninite. This chlorite is developed in the numerous fractures which traverse the garnet porphyroblasts.

The origin of these garnet-amphibolites which show many features in common with the eclogites will be discussed on a later page.

Prehnite-Amphibolite.

An amphibolite, developed as a band in the gneiss on the landward side of Boston Island, contains prehnite as the essential lime-mineral in place of plagioclase. The rock is intersected in part by white venules. These, on microscopical examination, are seen to consist of prehnite, associated with a little quartz presenting idiomorphic outlines. The ground-mass of the rock consists of prehnite, in which are embedded hornblende and magnetite, and granules of a monoclinic pyroxene. Acicular needles of actinolite are also present, and associated with quartz.

The prehnite of the veins shows the typical radiate arrangement which characterizes this mineral. The refractive index is less than 1·64, and has a range above and below 1·63. The mean refractive index is just under 1·63. The optical character is positive: but the birefringence is anomalous for this mineral, and, as seen in thin sections, does not exceed ·019. The mineral fuses in the ordinary gas-flame with intumescence, the fused mass being readily soluble in hydrochloric acid. The solution gives a strong reaction for calcium.

The source of the prehnite is presumably the plagioclase:

$$CaAl_2Si_2O_8 + Ca(OH)_2 + SiO_2 = H_2Ca_2Al_2Si_3O_{12}.$$

Calcium hydroxide could be derived from the pyroxene-amphibole conversion, but the source of the silica must be external, as quartz is associated with the prehnite itself.

(*b*) The Pyroxene-bearing Types: the Pyroxene-Granulites.

These rocks are closely related to the amphibolites. They occur as bands in the gneisses of Sleaford and Fishery Bay, and are represented in the dark bands which intersect the Boston-Island acid gneisses and granites. They can usually be distinguished in the field by their lighter coloration, as compared with the true amphibolites; although, if the content of hornblende is large, this is not readily possible. A number of these types will be described briefly.

(1) Pyroxene-Amphibolite from Sleaford Bay.

The constituents as seen under the microscope are hypersthene, augite, hornblende, plagioclase, orthoclase, magnetite, apatite, and pyrites. The two pyroxenes are seen in parallel intergrowth. In longitudinal section the inner pyroxene has straight extinction and the properties of hypersthene, and the outer zone has the properties of a monoclinic member—diopside or augite. In some cases this position is reversed, and the monoclinic member occupies the inner zone. The monoclinic pyroxene has developed a prominent diallagic lamination parallel to (100). A development of uralite at the edges of the pyroxene-grains is to be observed.

The hornblende has a habit such as to indicate it as a primary crystallization, and not replacing pyroxene.

Twinning in the plagioclase is not characteristic, and its composition points to calcic andesine. The potash-felspar is readily distinguished by its low refractive index, and for the greater part occurs in interstitial bands.

The order of abundance of the minerals in the rock is: plagioclase, augite and hypersthene, orthoclase, hornblende and magnetite, apatite, pyrites.

The composition in general is a mineralogical association of plagioclase, pyroxenes (monoclinic and rhombic), hornblende, and the accessories magnetite and apatite. In certain types additional minerals enter as accessories: orthoclase, biotite, garnet, quartz, pyrites, and zircon. The structure of the rocks is often quite granulitic, none of the constituents possessing any well-defined crystal-outline, and closely resembles that of the well-known granulites of Saxony. This granulitic habit is, however, not a constant feature of the rocks of this series, and in a number of the Sleaford types the minerals have a distinct gabbroid structure. The tabular character of the plagioclase is then a marked feature, and the twinning lamellation is universal.

With regard to the individual minerals, the monoclinic pyroxene occurs usually in pale greenish grains, not sensibly pleochroic. It is characterized by a high extinction-angle. In addition to the prismatic (110) cleavages, a parting parallel to (100) is commonly developed (diallage type). Occasionally, a second lamellation parallel to the base (001) is developed (salite type). Twinning on (100) may be sometimes noted. As inclusions, there may be present a dendritic type of iron-ore.

Hypersthene is a constant constituent of these rocks. It is readily distinguished from the monoclinic pyroxene by the straight extinction, low birefringence, and remarkable pleochroism in green and pink tints. The pleochroic scheme is:

X = pink, Y = light yellow, Z = green.

It bears, therefore, a distinct resemblance to the highly-ferriferous member of the enstatite-hypersthene series, amblystegite. The original amblystegite described by C. vom Rath, contained 25·6 per cent. of ferrous oxide. J. P. Iddings[1] records a hypersthene from Mount Shasta containing 22 per cent. of ferrous oxide with but feeble pleochroism; and V. Goldschmidt[2] records the same mineral in the contact-zone of the Christiania essexite with a ferrous-oxide content of 22·28 per cent. This mineral also shows no strong pleochroism, and that characteristic is doubtless one of the factors which induces him to note that hypersthene in other contact-rocks has quite probably been mistaken for andalusite.

It would appear, then, that the exceptionally strong pleochroism of hypersthene does not become apparent until the percentage of ferrous oxide reaches or exceeds 25 per cent., unless it is that an abnormal quantity of titanic oxide can produce a like effect with much lower iron contents, and the important influence of a titanium content in the monoclinic pyroxene is suggestive in this connexion.

The hypersthene, as noted above, is occasionally found in parallel intergrowth with a monoclinic pyroxene. Compared with augite, the hypersthene is particularly prone to alteration and decomposition, and in many cases it is represented only by pseudomorphs. The nature of these pseudomorphs calls for some remark. The commonest type of alteration appears to be a serpentinous product, optically negative and pleochroic in yellow and green tints with a double refraction approaching that of quartz. In addition, however, there appears in some examples a chloritic product. These alterations are often accompanied by a separation of iron oxide in the form of hæmatite or limonite, representing a further degradation of what were probably original magnetite granules:—

$$3MgFe\,(SiO_3)_2 + 2H_2O + O = H_4Mg_3Si_2O_9 + 4SiO_2 + Fe_3O_4.$$

Hornblende is a fairly-constant constituent of the pyroxene-bearing types, and is often indeed the dominant constituent, repre-

[1] 'Rock-Minerals' 1911, p. 304.

[2] 'Die Kontaktmetamorphose im Kristianiagebiet' Vidensk. Selsk. Skrifter, 1911, No. 1, pp. 321–22.

senting in such cases a transition from the true amphibolites wanting in the pyroxene minerals. Some of the hornblende is obviously derived from the pyroxene, as all stages can be seen. In these cases, it usually presents the distinctly fibrous appearance of uralite. Much of the hornblende, however, is original, and whatever its ultimate origin, it has crystallized *in situ* as such, and is often intergrown with the pyroxene. It has the properties of the normal amphibole of the amphibolites.

The pleochroic scheme is

X=pale greenish-yellow, Y=brownish-green, Z=green, $Z \wedge c = 16°$.

and the intensity scheme is $Z \geqq Y > X$.

The plagioclase occurs often in rounded grains—some showing twinning after the albite law, with occasional bands after the pericline type. Twinning may, however, be absent, and it is then (in the absence of cleavage) difficult to distinguish from quartz. Its composition is comparatively constant, and is within the limits of calcic andesine to labradorite. Inclusions of little prisms of apatite may be a marked feature.

In some of the rocks, notably those collected from the southern end of Boston Island, considerable strain is indicated in the plagioclase by a pronounced undulose extinction, and bent twinning lamellæ. As a result of stress, a secondary twin-lamellation is induced locally in originally untwinned grains. An alteration of the felspar with development of sericite (? paragonite)-flakes is sometimes observed.

Of the minerals which less commonly enter as constituents, quartz and garnet are noteworthy. Quartz is present in a number of these rocks collected from the south of Sleaford Bay, and is usually here an interstitial constituent.

When the garnet is present, the rock bears a strong resemblance to the garnet-amphibolites, the greater amount of the pyroxenic constituent affording the only noteworthy distinction.

Biotite may enter as an important constituent of some members. Often a distinct foliated appearance is given to the thin section by the development of flakes elongated uniformly.

Other examples show that some of the biotite is of secondary origin, and the association of the mica centreing around grains of magnetite adds further confirmation to this view.

The pleochroic scheme in all cases is

X=pale straw-yellow, Y=Z=deep red-brown (almost opaque).

VII. The Origin of the Amphibolites.

The petrography of the amphibolites described in the foregoing pages is essentially that of metamorphosed igneous rocks. This is indicated not only by their mineralogical composition, but also by their textures; for, despite the degree of metamorphism which these rocks have endured, palimpsest features are in many of them still recognizable. This is the case in such as show the blastoporphyritic or blastophitic texture. In other cases the textures

serve as no reliable guide in this determination. There are, however, certain peculiarities of some of these amphibolites which deserve further mention, and they will be now discussed.

The development of plagioclase and hornblende (usually with a subordinate amount of quartz-minerals), of which in the main these amphibolites are constituted, is to be regarded as the result of metamorphism of igneous rocks of general gabbroid or doleritic composition. The production of hornblende from an original pyroxene is probably not a simple change. In the first place, the amphibole has been totally recrystallized, and is not pseudomorphic after the original pyroxene. Its formation can be expressed in the simplest form by the following equation:—

$$\left\{\begin{matrix} 3n(CaMgSi_2O_6) \\ MgAl_2SiO_6 \end{matrix}\right\} + 2nH_2O = \left\{\begin{matrix} n(CaMg_3Si_4O_{12}) \\ MgAl_2SiO_6 \end{matrix}\right\} + 2nCa(OH)_2 + 2nSiO_2.$$

In this case the amphibole is shown to contain the Tschermak silicate, the alumina in many analyses of hornblende conforming to this constitution. It is to be noted that the resulting amphibole is more aluminous than the original pyroxene from which it is derived, and this is in harmony with typical analyses of amphibole and pyroxene, the pyroxenes of many basic igneous rocks showing a comparatively low alumina-content. With the release of lime from the pyroxene-molecule, silicate is set free, and appears as quartz in the resulting amphibolite. In some amphibolites this lime appears as titanite, and it is probable that the pyroxene is the original source of the titanium, thus

$$Ca(OH)_2 + TiO_2 + SiO_2 = CaTiSiO_5 + H_2O.$$

Obviously, of the silica released in the main reaction, only that amount which is molecularly equivalent to the titanium not absorbed in the newly-formed amphibole, is taken up in sphene. The characteristic association of hornblende and sphene in some of these amphibolites (especially in the garnet-amphibolites) is thus to be explained.

Of subsidiary reactions which may assist in amphibolization we may note the following:—

$$(1)\ 2MgSiO_3 + CaMgSi_2O_6 = CaMg_3Si_4O_{12}$$

$$\text{and } (2)\ CaMgSi_2O_6 + MgAl_2SiO_6 = CaMg_2Al_2(SiO_4)_3.$$

Of (1) it may be noted that any enstatite- or hypersthene-molecules present in the original pyroxene substance would, with the diopside-molecule, yield tremolite. It seems possible that this reaction might take place in rocks containing individual hypersthene and within the limits of diffusion of a neighbouring monoclinic pyroxene, thus affording an explanation of the absence of anthophyllite in those amphibolites the analyses of which correspond to hypersthene-bearing dolerites.

Lastly (2) may be taken to represent the change, where the amphibole substance is represented as containing the syntagmatite-molecule, which, according to R. Scharizer,[1] is the case for many amphiboles.

[1] Neues Jahrb. vol. ii (1884) p. 143.

Rocks which represent a higher grade of metamorphism than the common type of amphibolite are observed among the garnet-amphibolites (or, more correctly termed, 'hornblende-eclogites'). These rocks have been derived from true pyroxenic eclogites, and the pyroxene which they now contain is not the original pyroxene of the igneous rock, but this mineral recrystallized.

L. Hezner[1] and U. Grubenmann[2] have shown that the garnet of the eclogites is to be regarded as the result of the interaction of the original pyroxene with plagioclase, or in some cases of olivine with that mineral, and the equation to represent this change need not be represented here. It is sufficient to note that, in the former case, an essential bye-product is silica, and appears as quartz.

The true pyroxenic eclogites are characteristic rocks of Grubenmann's 'Kata-zone,' and the hornblende-eclogites have developed under conditions in which shearing-stress is more in action. There is, however, another source from which the garnet of these rocks may be derived, which involves a rearrangement of the pyroxene-molecule without the interaction of the felspar-molecule. This may be concisely stated in the following equation:—

$$\left\{\begin{matrix} xCaMgSi_2O_6 \\ MgAl_2SiO_6 \end{matrix}\right\} = CaMg_2Al_2Si_3O_{12} + (x-1)\ CaMgSi_2O_6.$$

Of this reaction there is fairly conclusive proof in certain metamorphosed dolerites which will be dealt with later, for the metamorphism of these rocks is accompanied by reaction-rims of the individual minerals, but with more or less preservation of the original igneous textures, enabling us to see the transformations in progress. It is, therefore, possible that in the pyroxene-eclogites some of the garnet has originated in this manner.

In the hornblende-eclogites of the Flinders Series, the formation of amphibole from the pyroxene of the true eclogite has evidently proceeded at a greater rate than the garnet degradation; or, at least, garnet is more stable under the conditions that were then prevailing. Thus the garnet is now only showing signs of instability, as represented by the diablastic intergrowths of hornblende and plagioclase which fringe its borders. These, by their manner of development, show that the process is one of degradation rather than of formation of garnet, and this change may be represented as follows:—

$$\left\{\begin{matrix} 2CaMg_2Al_2Si_3O_{12} \\ Ca_3Al_2Si_3O_{12} \end{matrix}\right\} + 2H_2O = 2CaAl_2Si_2O_8 + \left\{\begin{matrix} CaMg_3Si_4O_{12} \\ MgAl_2SiO_6 \end{matrix}\right\} + 2Ca(OH)_2.$$

It has already been noted that the presence of a subordinate amount of quartz as a general constituent of amphibolites is to be regarded as the normal result of metamorphism.

There are, however, present in the Flinders Series amphibolites (of which a petrographic description has been given) that contain a greater percentage of quartz than can be ascribed to any

[1] Min. Petr. Mitth. vol. xxii (1903) pp. 473, 505.
[2] 'Die Kristallinen Schiefer' 1910, p. 53.

pyroxene-amphibole conversion. This quartz is very generally accompanied by orthoclase, which in the normal type of amphibolite is either absent or very sparingly present. The existence of these quartz- and orthoclase-bearing amphibolites calls therefore for some remark.

At first sight, a number of explanations can be proffered. Either the quartz-orthoclase amphibolites represent hybrid rocks in which a normal amphibolite has been intimately penetrated by quartz-and-orthoclase solutions of the invading magma; or these rocks are the metamorphosed equivalents of igneous rocks slightly more acid than the normal doleritic type; or lastly, they are sediments now highly metamorphosed. Of these explanations, the second is the most probable, and is in agreement both with their general composition and their mode of occurrence in the field.

With regard to explanation (1), it is true that the amphibolites have in many places been penetrated by fine strings of pegmatitic solutions from the granite-gneisses, and that the amphibolites may thus locally be converted into hornblende-gneisses. But it is also to be remarked that the amphibolites with which I am now dealing show this content of orthoclase and quartz throughout their mass, and in positions remote from any pegmatitic veining. For example, in many cases such amphibolites are veined only at their borders, the interior and centre of the band being completely free from any igneous intrusion, yet the centres of these bands show a remarkable uniformity of composition, the minerals in question being present in such an association with the hornblende and plagioclase as precludes any external source. This is the more convincing when the structure of the rock in question shows the presence of potash-felspar and quartz in an undestroyed blastophitic ground-mass, or other typical residual texture.

It is to be noted that hybridism has played a part in the constitution of the amphibolites, as I have already remarked; but this process is not capable of accounting for the features of the amphibolites now under discussion.

It is of interest to note in the former connexion, that the felspars of the veins and strings of granite very generally show an advanced state of decomposition, while the felspars of metamorphic origin are characteristically clear and free from decomposition, although there are exceptions to this condition. This differentiation in the susceptibility of weathering of felspars of igneous and metamorphic origin respectively, is of wide application, and finds a parallel in contact-metamorphic areas around plutonic intrusions.[1] The reason for this is at first sight not very clear, but a partial explanation may perhaps be found in the fact that a removal of inclusions susceptible to decomposition accompanies the recrystallization of metamorphic felspar.

It was of importance, in the elucidation of these quartz-orthoclase amphibolites, to determine the chemical composition of a typical

[1] See A. Harker & J. E. Marr, Q. J. G. S. vol. xlvii (1891) p. 296.

member, in order that a comparison with other rocks might be afforded. A chemical analysis of an amphibolite from the gneisses near Point Boston (hundred of Lincoln) was, therefore, made, and this has already been set forth on p. 101, together with some comparative analyses.

The amphibolite is placed with other typical igneous rocks in a well-defined subrang in the C. I. P. W. classification: namely, II. 4.3.3, and, among the analyses quoted for comparison, it bears the closest relation to the quartz-gabbro of Georgia. Chemical analysis, therefore, is in harmony with the view that the amphibolite is a metamorphosed igneous rock, perhaps most comparable with a quartz-gabbro.

The recent work of F. D. Adams & A. E. Barlow,[1] on the amphibolites of the Laurentian area of Ontario, has shown that there are certain amphibolites derived from the metamorphism of impure calcareous or calcareo magnesic sediments, which are comparable both chemically and petrographically with amphibolites of undoubted igneous origin. That amphibolites have been derived by this process, there is in the Ontario region abundant field-evidence; for the rocks show that gradation of composition which is at once characteristic of sediments, and the clue to their origin.

At Sleaford Bay there are metamorphosed impure dolomites, consisting of diopside, bytownite, and microcline with scapolite, and as inclusions in the Flinders gneisses, diopside-rocks of undoubted sedimentary origin; but, among these metamorphosed calc-magnesian silicate rocks, there are none resembling in any particular true amphibolites. This perhaps cannot be regarded as conclusive evidence; but negative evidence must here be considered an important factor. Moreover, there are no amphibolites in the Flinders Series showing that variation of mineralogical composition which is to be expected in amphibolites derived from calcareo-magnesic sediments. One of the important features of large bands of the amphibolites is their uniformity of composition throughout the mass, the reverse of which is the dominant characteristic of the metamorphosed Sleaford sediments.

For a like reason, any conception of the amphibolites which represents them as sediments contaminated with basic volcanic material utterly lacks evidence, and is in addition rendered very improbable from the chemical composition.

The conclusion is, therefore, enforced that these amphibolites are in virtue of their chemical and petrographic composition, metamorphosed igneous rocks of slightly higher acidity than the normal gabbroid or doleritic type of intrusive.

The relationship of the analysed amphibolite with the igneous rocks, quoted in the table on p. 101, may be illustrated by a graphical representation of their analyses, utilizing an adaptation of the Osann

[1] Mem. Geol. Surv. Canada, No. 6 (1910) pp. 104–16.

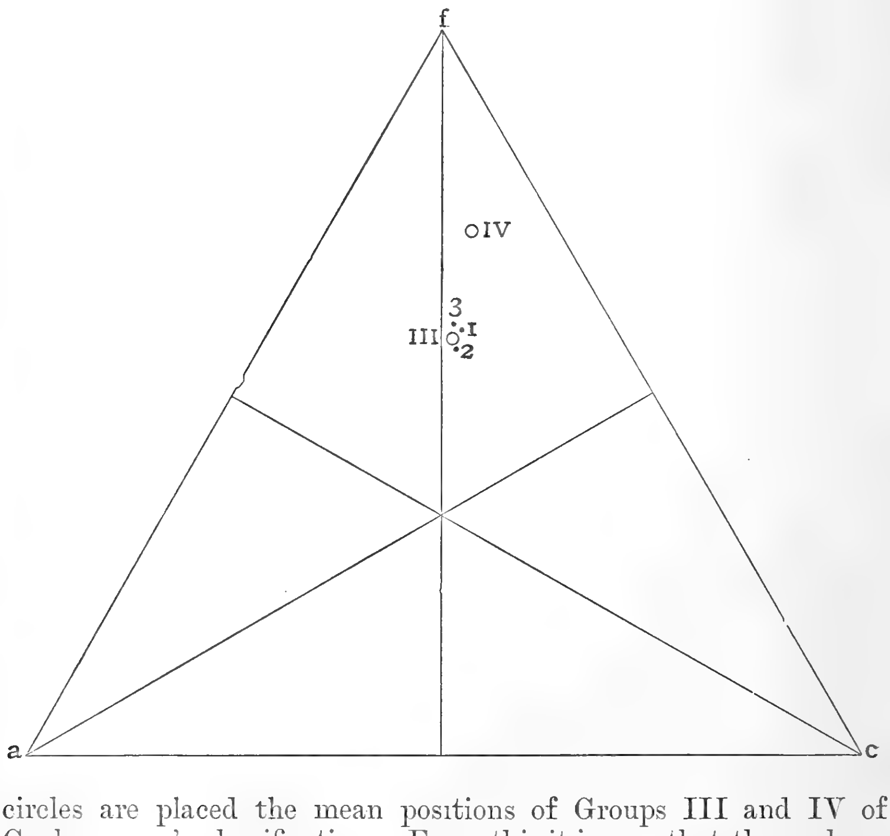
triangular diagram. It will suffice to take, in addition to the amphibolite analysis, those of the quartz-gabbro of Georgia and the diabase of Somerset County (New Jersey).

The parameters of these rocks, when calculated, are:—

	a	c	f
(i) Point Boston amphibolite	3·6	4·9	11·5
(ii) Georgia quartz-gabbro	3·9	5·2	10·9
(iii) New Jersey diabase	3·7	4·5	11·8

In the accompanying diagram, the positions of these rocks are indicated by the points 1, 2, and 3, respectively (fig. 8). In plain

Fig. 8.—*Osann projection of the Boston amphibolite, and igneous rocks comparable therewith.*



circles are placed the mean positions of Groups III and IV of Grubenmann's classification. From this it is seen that the analyses group themselves in proximity to the mean position of the plagioclase-gneisses (III), and thus show some affinity to the dioritic group of igneous rocks.

Attention may here again be drawn to the description of an amphibolite-band in the Kirton-Point area, which is a foliated amphibolite at the border, but near the centre shows a much more massive structure, and is in fact a partly-uralitized micropegmatitic dolerite (p. 102). There is thus both field and chemical evidence to

support the suggestion previously made that the quartz- and orthoclase-bearing amphibolites are derived from dolerite rocks in which quartz and orthoclase figured as constituents, in some cases certainly as micropegmatite.

With this brief treatment of the petrographic nature of the amphibolite members of the Flinders Series, the important subject of source and origin remains for consideration. If we confine our attention for the moment to the amphibolites which yield indubitable evidence of their anterior origin as compared with the granite-gneisses, the evidence on which this is based may be recapitulated as follows :—

(1) The amphibolites are invaded and broken up by the granitic and pegmatitic veins and dykes.
(2) These veins may intrude along well-defined foliation-planes, or break abruptly across them.
(3) The disruption of amphibolite-bands into smaller lenticles and streaks can be traced in innumerable examples.
(4) Wherever the amphibolites possess an elongate habit, their longer axes are in general arranged parallel to the flow-structure in the surrounding gneiss, which bends round them at their extremities.
(5) The amphibolites have in some cases been rendered plastic under the influence of the thermal metamorphism, being drawn out in the direction of the flow-structure in the gneiss, and conforming to its intricate contorted foliation.

This collective evidence is overwhelmingly in favour of these amphibolites being earlier inclusions in the acid gneisses, and any posterior dyke-origin is inadmissible. Two possibilities remain to be discussed :

(i) The amphibolites are basic segregation-products of the acid gneisses.
(ii) They represent earlier consolidated rocks which have been previously metamorphosed, and engulfed by the later gneisses.

Neither by their form nor by their relationship to the granite-gneisses, do these amphibolites correspond to basic segregations, and any interpretation on the lines of explanation (i) can be dismissed. That they are earlier consolidated masses which have been metamorphosed and subsequently engulfed by the granites remains a conclusion supported by all the evidence that now exists.

In the first place, it is to be remarked that the metamorphism had been accomplished prior to their incorporation, for by this means alone can be explained the fact that these planes of foliation have been utilized as planes of maximum invasion by the liquid magma, thus necessitating an antecedent foliation.

In accordance with this view is the evidence that the long and narrow bands have their foliation and elongation in parallelism; for the stoping action that incorporation demands must of necessity have taken place along those directions in which separation was most readily accomplished. Such foliation-planes are thus planes of minimum cohesion. On the other hand, those amphibolites

in which no unidirectional foliation can be observed are often quite irregular in shape, and are penetrated at haphazard by the invading magma. In some cases this massive texture has been such as to resist almost completely the efforts of the magma to invade it. Those inclusions which have yielded by plastic deformation to the flowing movements in the gneiss have sometimes quite remarkable and intricate shapes.

Whether an amphibolite inclusion shall show signs of plasticity is doubtless dependent on more than one factor: for example, the length of time during which the inclusion is suspended in the liquid magma (and so the extent of thermal metamorphism), the severity and magnitude of the movements in the flowing gneiss, and the degree of metamorphism impressed on the rock prior to its disruption from the parent mass, may be considered valid indicators of the extent of plastic deformation. Examples of plastic deformation following on lit-par-lit intrusion can be seen in many bands. Here pegmatite strings have been contorted and drawn out into isolated lenticles, though plasticity may be well developed in masses which show but little sign of magmatic intrusion.

In the foregoing paragraphs the interpretation of the amphibolites, as a whole, as metamorphosed igneous rocks is of some assistance in any attempt to locate the source of these inclusions.

If we look to the series of pre-existing sediments now highly metamorphosed—the Hutchison Series—for the source of these amphibolites, there is found no adequate supply. There are, it is true, among the sediments some basic dykes and sills; but these form quite an inadequate percentage of the series. Moreover, it is not known whether these dyke-rocks are not 'post-gneiss' in origin. In the absence of any definite area now exposed to view for the source of these inclusions, an attempt to trace their history further back must be somewhat speculative, but from general considerations I may offer suggestions which appear to have some plausibility.

It may be suggested that the amphibolite inclusions represent the disrupted portions of an older igneous terrane, which was intruded in a deep-lying portion of the crust, into the pre-existing country rocks, possibly the members of the Hutchison Series of which only fragmentary remains are now visible, or some older series still of which there is no record. In general these amphibolites are of gabbroid or doleritic composition, so that in the older intrusions, from which these inclusions are derived, gabbroid rocks were largely represented. It seems the more probable that these earlier gabbroid intrusions belonged to the same orogenic epoch, or diastrophic period, as that which finally culminated in the irruption of the granite-gneisses. On this view the igneous equivalents of the amphibolites are thus comagmatic with the acid granites.

It is not difficult to conceive of earlier and deep-lying intrusions

into the supercrust, which cooled and consolidated prior to the irruption of the more acid and so more lately evolved granite-gneisses. With the intrusion of the latter into the gabbroid rocks already crystallized, these basic rocks would be metamorphosed, and under a stoping action would be incorporated within the flowing gneiss. This metamorphism, as might be expected under such conditions, has not been of the pure thermal type, but one in which shearing stress has also played a part. In this way only is the unidirectional foliation of the amphibolites to be explained, and this metamorphism was therefore accomplished prior to the rifting-off of the amphibolite-bands, for with the subsequent engulfment, the inclusion is subject to pure thermal metamorphism under hydrostatic pressure.

So far we have considered that large proportion of amphibolites which show indubitable evidence of intrusion by the gneisses. It is, of course, not possible to prove intrusive relationships in every basic amphibolitic band. In several the junction with the gneiss cannot be seen, owing to some accidental circumstance. Again, it is noteworthy that some of the massive types show no visible injection by the gneiss, and the border-zone may be quite sharp, or the parallelism of the elongated bands with the foliation (which is very generally observed) may be somewhat departed from. From the point of view of inclusions showing these characters, it may well be that a more massive type of inclusion shall resist pegmatitic invasion to a greater degree than one already foliated; and, so far as parallelism of gneissic foliation and elongation is concerned, a departure may indicate simply that complete orientation had not been effected.

The point to be remarked is, that absence of evidence of invasion, a not strictly-parallel arrangement of inclusion and foliation, and the presence of a sharp, well-defined border-contact, such features being shown by a number of amphibolites, cannot be necessarily taken as evidence of a posterior dyke-origin. This is more especially the case where the large majority of amphibolites give evidence of their anterior origin by those properties which have already been discussed. It would be idle to deny, however, in a region of such complexity as this, the absence of posterior dyke-origin.

With regard to these particular bands in the gneiss, the question of an anterior or posterior origin must of necessity at present be left an open question, for the field-evidence adduced is capable of a dual explanation; nor does the microscopic evidence shed further light on the origin of such a band, which may be identical in composition and texture with a band in which all the requirements for an anterior origin are fulfilled.

A posterior dyke-origin is rendered the more probable, when the trend of the band is violently opposed to the flow-structure, and when the contact is definitely an intrusive one as seen by branching veins or other similar structures entering the surrounding gneiss. There are a number of bands in the gneiss of Boston Island which seem to fulfil these conditions; but in no other locality have there

been observed amphibolites which can be safely interpreted by their field-occurrence as posterior dykes.[1]

Of these dominantly pyroxene-bearing basic bands, those met with in the Sleaford area are true inclusions, as seen from their relations to the surrounding gneisses. These have been petrographically described under the heading of pyroxene-granulites. There are, however, in addition to these, certain basic bands of dyke-origin comagmatic with the gneisses, and of basic charnockite composition. Such have been observed cutting the pyroxene-bearing granites of the hundred of Flinders near West Point.

With regard to the earlier pyroxene-granulites, there are no criteria of absolute certainty that can be utilized to determine the character of crystallization, whether igneous or metamorphic. Their granulitic texture, the frequent absence of twinning in the plagioclases, and the presence of garnet, are certainly not valid indicators of a metamorphic recrystallization. Identical features can be recognized in the well-known igneous charnockite series of India.

VIII. The Metadolerites of the Lincoln Area.

(*a*) General Description.

Dark bands of doleritic aspect are intercalated in the acid gneisses at Kirton Point; and on the western shores of Boston Island, as at other localities, there are rocks which resemble these, and are representatives of this group.

Dealing now with those the doleritic origin of which is undoubted, I may first notice those of Kirton Point. Sir Douglas Mawson obviously refers to one of these rocks in his short note on the geological features of Eyre Peninsula,[2] where he records

> 'the occurrence of a biotite-bearing pilotaxitic dolerite-dyke about 30 feet wide running with the series . . . . it cannot be very ancient, certainly not comparable in this respect with the intruded rocks.'

A study of thin sections of this and related bands, however, reveals that these rocks have undergone a high grade of metamorphism, a conclusion wholly unsuspected from a mere examination of hand-specimens, and one which is likely to shed quite another light on the rocks, as regards both their origin and their antiquity, in comparison with the statement quoted above. The microscopic study of this series is one of extreme interest, and a detailed account of their petrographic features is therefore warranted.

[1] Petrographic treatment of these posterior dyke-rocks is delayed until a further study has been made of their occurrence in the field.

[2] Trans. Roy. Soc. S. Austr. vol. xxxi (1907) p. 73.

(*b*) Petrography.

No. 45.—Under the microscope, this band shows a distinct blastophitic texture, for the ophitic character is now only a 'relict' feature. The constituent minerals are plagioclase, pyroxene, both monoclinic and rhombic, magnetite, hornblende and biotite, and a little pyrites.

The felspar is developed in laths penetrating the augite, and shows usually albite and Carlsbad twins. A pericline lamellation is also developed. Much of the felspar is filled with a minute dust, rendering it semitransparent. Under a high power these inclusions are seen to consist of minute granules which are colourless, and have a refractive index greater than the enclosing felspar. They are not isotropic, however, and in the positions of extinction of the felspar transmit light. They are probably pyroxenic granules. These inclusions may sometimes be confined to the centres of the felspar-laths, the dusty centre being bordered by a clear area. In some of the laths they are completely absent, and in these strings of pyroxene-granules often occur. This clearing of the felspars is probably related to the recrystallization which has been involved.

The felspar is a labradorite, symmetrical extinctions to a value of 33° being obtained in suitably oriented laths. Some zonary structure is present.

The augite envelopes the felspar-laths, and has the typical appearance of the augite present in normal dolerites, showing a dust of oriented inclusions. These inclusions are rod-like in section, and some appear to be oriented parallel to the optic axial plane (010), others again in a plane at right angles to the prismatic cleavages. They are too minute for definite determination. A distinct lamination of the diallage variety is observed in this augite, and a curved or rosette-like arrangement of the grains may be apparent.

At the periphery of the augite-grains, the pyroxene is often converted into a clear granulitic aggregate devoid of any dust-like appearance. Such aggregates consist of granules of monoclinic pyroxene with a slight greenish tint, and sometimes feebly pleochroic, as observed under a high power. In some cases, only a small fraction of the original dusty pyroxene is left as a 'relict' mineral. The pyroxene here has been clearly recrystallized with a granulitic habit, and in contact with felspar where there has been an approach to a crystal outline, it is the augite not the felspar that is idioblastic: a feature wanting in the unaltered dolerite. There are further granulitic aggregates in which an enstatite or bronzite is the dominant mineral, the granules being characterized by a low double refraction and straight extinction without perceptible pleochroism. The monoclinic pyroxene is often associated in granules in these and also some 'relict' augite. This enstatite is not primary but secondary, and must have been derived from an original enstatite which has been recrystallized. The hornblende and biotite present are closely associated with the grains of iron-ore. Both these silicates are of secondary development. The

magnetite has usually formed an inclusion in the primary augite. A typical association is a magnetite-grain acting as a nucleus to a peripheral zone of red-brown strongly-pleochroic biotite, and this passes out into an amphibole-zone.

Another rock (No. 44), which appears to be related to that just described, shows a great development of hornblende, and the blastophitic texture is wanting. The constituents are hornblende, plagioclase, pyroxene, and a few grains of iron-ore.

The texture is typically granoblastic; but there are a few lath-like felspars with irregular borders, which may represent the last survival of an ophitic structure. This is further suggested by the fact that some of these carry minute granular inclusions. The centres of these irregular laths are occupied by strings of hornblende parallel to their length. The amount of plagioclase is considerably less than in No. 45, and there is a noticeable paucity of iron-ores.

The granulitic pyroxene appears to be mainly an enstatite, and types of aggregates similar to those seen in No. 45 are observed.

The central strings included in the lath-shaped felspars, which are pyroxene in No. 45 and hornblende in No. 44, are not unlike the metamorphosed equivalents of chlorite-strings, produced in the weathering of felspars of igneous rocks.

No. 85.—The same type of metamorphosed dolerite occurs in bands in the gneisses of Boston Island. These are well represented on the south-western shore. No. 85 in hand-specimens closely resembles No. 45. Under the microscope, however, there are important additional features which emphasize the high-grade metamorphism that these rocks have undergone. The constituents are augite, plagioclase, hypersthene, garnet, magnetite, biotite, and a small amount of amphibole.

The primary augite is characterized by its diallagic (100) lamination and the development of 'schiller' inclusions. The nature of these is here more evident, and they consist of magnetite or titanomagnetite granules. The crystals of augite may again show a rude radiate arrangement.

The plagioclase is of the same composition as in No. 45—a labradorite with symmetrical extinction of 33°. This mineral was separated from the remaining constituents by means of bromoform solution. Under a high power it was found to be crowded with a minute black dust rendering it quite dark in colour. The refractive index exceeds 1·55, but is less than 1·57. In a liquid of refractive index of 1·56, grains are present with an index both above and below this value. The specific gravity exceeds 2·69, but is less than 2·72. These properties, together with those ascertained in thin slices, indicate labradorite. The range, however, in view of the pronounced zoning, is from a basic andesine to a labradorite-bytownite. It shows twinning after the Carlsbad, pericline, and

occasionally the Baveno laws—in addition to the albite lamellation. The newly-formed minerals include secondary augite, hypersthene, and garnet. As before, the secondary granulitic augite forms a border to the 'relict' augite. All fine dusty magnetite has been eliminated, or at least has coalesced into larger granules, which become associated with the secondary augite-granules.

The garnet is likewise developed in granular fashion, but, when wholly enclosed in felspar, quite well-developed idioblastic dodecahedra are the rule. It may occur as a corona or border to the pyroxene, intervening between this mineral and the plagioclase-felspar (see fig. 9, p. 120). Very characteristic, however, is its presence in granulitic aggregates or complexes consisting of garnet, augite, and hypersthene, with magnetite and usually biotite. These complexes may be developed around central grains of diallagic primary augite, the garnet often then forming an outer border to the felspar (see fig. 10, p. 120). The secondary augite of these complexes is typically granulitic, with high double refraction, oblique extinction, and not sensibly pleochroic. The hypersthene is developed with the same habit, but shows a strong pink to green pleochroism, is optically negative, and has straight extinction. The garnet is likewise granulitic, and sometimes presents a core of opaque grains of magnetite. In some of the grains occur inclusions of microvermicular pyroxene. Magnetite may also appear as a corona of grains around the pyroxene-granules.

The absence of quartz from these complexes, and indeed from the whole rock, is of noteworthy significance. There appears to be only one interpretation of these aggregates: namely, that they are the products of recrystallization of an original primary augite.

The small amount of hornblende present replaces the pyroxenes, for the habit is distinctly preserved. Biotite, too, is a secondary product; but its development is more clearly associated with the iron-ore, from which it has presumably derived some of its iron supply. It is of the characteristic red-brown type.

The specific gravity of this rock is 3·13.

No. 221.—This represents another band from the same locality. It resembles those previously described in many particulars, but is characterized by an additional mineral, olivine. This is developed in colourless grains with a high refractive index. Characteristically along cracks are seen aggregates of magnetite-grains. Serpentine pseudomorphs after this mineral are present, and their strong green colours are indicative of a high iron-content. A yellowish-brown type of serpentine is also occasionally met with, and has no perceptible pleochroism. Suitable sections of the olivine show that it possesses negative birefringence, and its ferrous content must therefore exceed 12 per cent. Many of these olivine-grains show a border of pleochroic hypersthene, which in some cases is granulitic. It appears probable that this border must represent a primary crystallization, indicative of the conditions of mobile

Fig. 9.—*Garnet and secondary pyroxenes developing from original augite.* × 50.

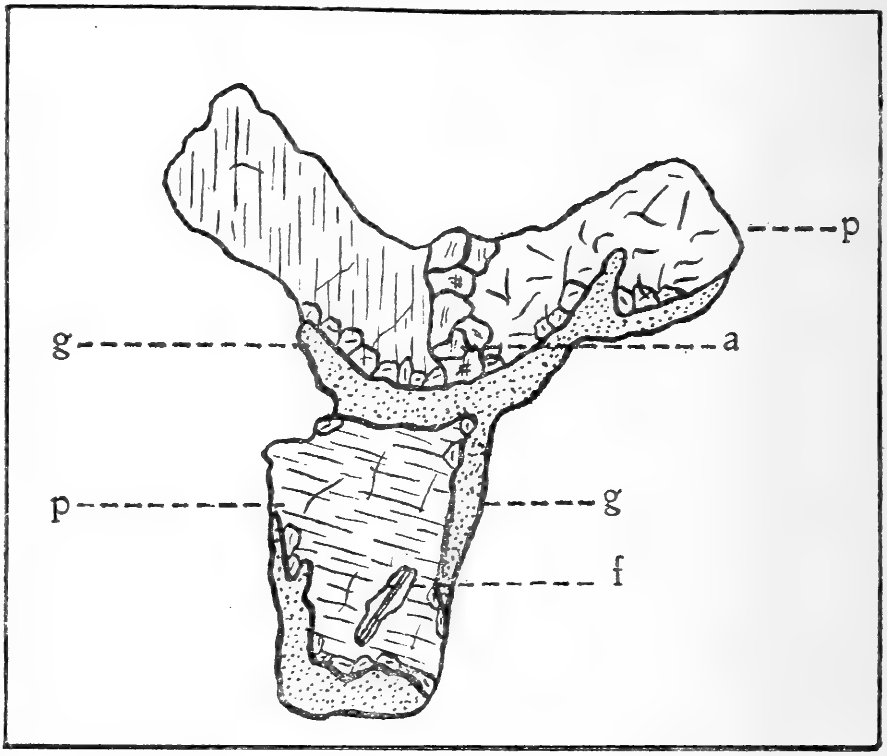
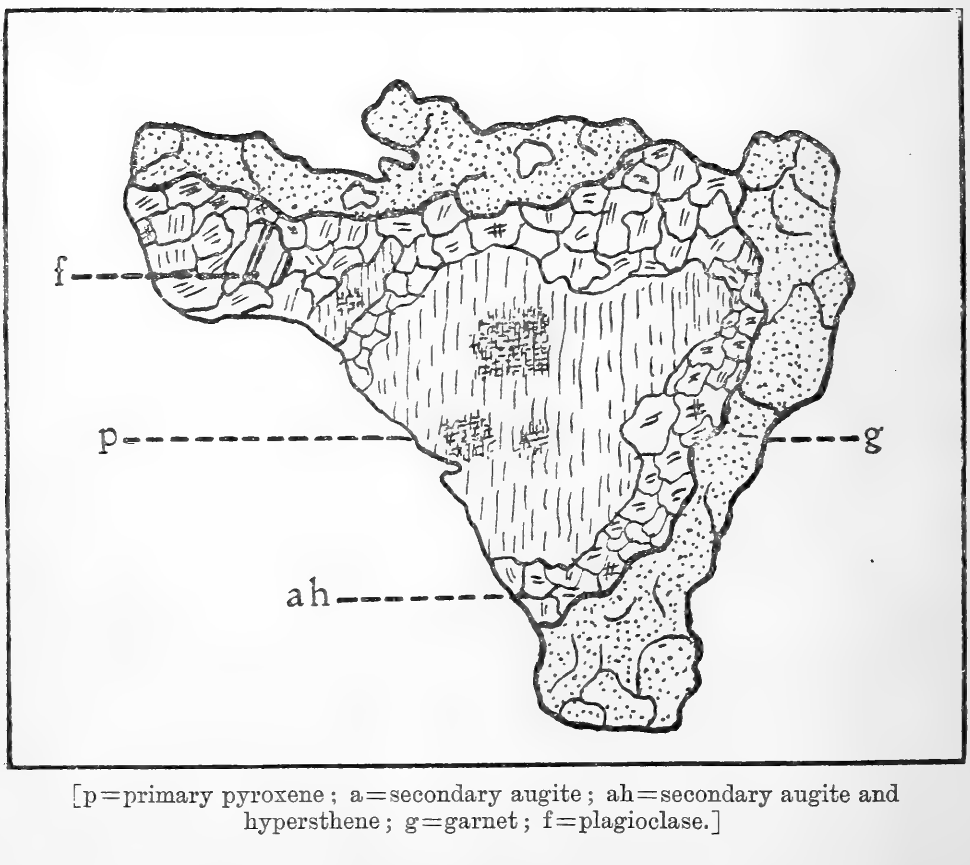


Fig. 10.—*Peripheral development of garnet.* × 50.



[p=primary pyroxene; a=secondary augite; ah=secondary augite and hypersthene; g=garnet; f=plagioclase.]

equilibrium prevailing in the crystallizing magma; as shown in the equation

$$MgFe(SiO_3)_2 \rightleftarrows (MgFe)SiO_4 + SiO_2.$$

N. L. Bowen & O. Andersen have shown that the resorption of olivine-crystals with the development of reaction-rims of enstatite is a factor involved in the normal crystallization of basaltic melts, as a simple result of cooling.[1] The hypersthene border has all the appearance in the granulitic type of having been recrystallized in course of metamorphism.

Garnet is not so abundant a constituent of this rock as of No. 85, but its relations are again the same.

In another band from the same region (No. 89) a further change has developed. The constituents are again plagioclase, augite, hypersthene, magnetite, hornblende, and biotite.

The differences to be noted are the great percentages of hornblende and a changing texture. The amphibole is now the most important ferromagnesian mineral, and the blastophitic texture is all but lost, a more granoblastic arrangement being now impressed. The garnet-pyroxene complexes are, however, still preserved, and the granulitic character of the pyroxene remains to indicate the relationship with the rocks previously described.

The actual size of grain of the amphibole tends to be a little greater than in the pyroxene; but traces of the pyroxene-amphibole conversion are still preserved, and the hornblende has been formed in this way. All stages of this transformation can be noted.

The microscopical features of the garnet-pyroxene complexes are identical with those of Nos. 85 and 221. All the 'relict' augite has disappeared; but some of the larger hornblende-grains may represent this transformed.

This rock, therefore, presents the features of the preceding types on which a hornblendization has been superposed. This hornblendization can most readily be accounted for by a development in a declining stage of metamorphism: that is, when a decline of metamorphism from its maximum had set in, being an adjustment of equilibrium accompanying the cooling of the rock.

An interesting type from Cape Euler, south of Tumby Bay, presents a further feature of interest. The texture is typically blastophitic, but in addition there are present a number of granulitic aggregates of quartz and orthoclase, and the rock exhibits many of the characters of the quartz-dolerites.

'Relict' augite is present, recognizable by its inclusions and fibrous diallagic appearance. The secondary granulitic pyroxenes include both the monoclinic and rhombic varieties, as before.

[1] 'The Binary System $MgO–SiO_2$' Amer. Journ. Sci. ser. 4, vol. xxxvii (1914) pp. 487–500.

There is a large development of green hornblende, although this is not original, but developed paramorphically after the pyroxenes. The accessories are magnetite and some biotite. The plagioclases still show the original dusty inclusions. There has been no production of garnet in this rock. The original rock was undoubtedly of a quartz-doleritic type.

(*c*) Chemical Changes induced by Metamorphism.

The metamorphic changes which these dolerites have undergone are essentially those of the highest grades of metamorphism. A few remarks as to the probable nature and genesis of these newly-formed minerals are necessary. It is clear that the original rocks were essentially doleritic in character, the constituent minerals of which as a group were plagioclase, augite, hypersthene, enstatite, and olivine. Magnetite formed an accessory, present both in grains, and as a dust to the primary pyroxenes. As a result of metamorphism, the original pyroxenes are recrystallized with a granulitic habit in which the dusty magnetite has been expelled, with coalescence to newly-formed grains. The felspars too have been involved in the recrystallization, and the clear areas of this mineral are indicative of a similar coalescence of inclusions. In some of this recrystallized felspar the blastophitic texture has been retained; but there has also been a reconstruction with destruction of this texture, yielding a more typical granoblastic arrangement.

With the appearance of garnet, chemical changes are involved, and the same remark applies to the development of biotite aggregating around grains of iron-ore. The production of garnet by metamorphism in rocks of this class is known to take place in several ways. The possibilities are best expressed chemically, and the reactions can be stated in the equations that follow:—

(1) Interaction of felspar and pyroxene.

$$CaMg(SiO_3)_2 + CaAl_2Si_2O_8 = Ca_2MgAl_2Si_3O_{12} + SiO_2.$$

(2) Interaction of felspar and olivine.

$$Mg_2SiO_4 + CaAl_2Si_2O_8 = CaMg_2Al_2Si_3O_{12}.$$

(3)

$$\underset{\text{(Aluminous augite.)}}{\begin{matrix} xCaMg(SiO_3)_2 \\ MgAl_2SiO_6 \end{matrix}} = \underset{\text{(Garnet.)}}{CaMg_2Al_2Si_3O_{12}} + \underset{\text{(Diopside.)}}{(x-1)CaMgSi_2O_6}.$$

Reactions of Types 1 and 2 have been used by Hezner [1] & Grubenmann [2] in their treatment of the eclogites, the typical garnet of this rock being considered as a result of the interaction of plagioclase with the metasilicate or orthosilicate molecule. In those rocks the felspar-pyroxene interaction is attested by the associations of these minerals, and receives further confirmation in the fact that the inevitable bye-product of such a reaction (namely, silica) is represented by quartz.

[1] Min. Petr. Mitth. vol. xxii (1903) p. 473.
[2] 'Die Kristallinien Schiefer' 1910.

While in the rocks under discussion the garnet is often developed as a border to original augite, and intervening between this mineral and felspar there is a conspicuous absence of quartz, this reaction, however probable the associations may appear, cannot represent the change which has resulted in the production of garnet. The absence of quartz in all those rocks in which garnet is a constituent is indicative that this type of reaction has played no important part.

Of the reaction of Type 2 we can speak with less certainty. Olivine is known as a constituent of a number of these rocks, but here the associations requisite to conform to this type have not been observed. In some cases this change may, however, have proceeded to completion, and there are certain features which suggest that this reaction has sometimes played a part. Especially is this so where garnet-grains are developed isolated in the plagioclase. It may well be that these garnet-crystals represent original olivine which has reacted with felspar to yield this mineral, the felspar becoming richer in the albite molecule as a consequence.

There can be little doubt, nevertheless, that reaction 3 has actually been in progress. The typical garnet-pyroxene borders to 'relict' pyroxene are most readily explained by this reaction. The secondary granulitic monoclinic pyroxene, which is of a pale-green colour, would appear to represent the diopside of this equation, or at least the pyroxene poorer in aluminous constituents. A secondary pyroxene of hypersthenic composition is an important constituent of these aggregates in many cases, and the evidence suggests strongly that this hypersthene is also a product of the recrystallization of the original augite. It is unmistakably associated with the granulitic borders to an original monoclinic pyroxene, besides being developed in the complexes in which the 'relict' pyroxene has ultimately disappeared (see fig. 11, p. 124).

These coronas around 'relict' augite, consisting of the three above-mentioned minerals, and in which no constituent takes part other than the coalesced aggregates of magnetite (with some biotite), are most readily explained by a derivation from the nuclear pyroxene. It would appear, therefore, that the hypersthene molecule is a constituent of the original augite, and the equation expressing this disintegration of the pyroxene is as follows:—

$$\underset{\text{(Augite.)}}{\left\{\begin{array}{l} x\mathrm{CaMgSi_2O_6} \\ \mathrm{MgAl_2SiO_6} \\ y\mathrm{MgSiO_3} \end{array}\right\}} = \underset{\text{(Diopside.)}}{(x-1)\mathrm{CaMgSi_2O_6}} + \underset{\text{(Garnet.)}}{\mathrm{CaMg_2Al_2Si_3O_{12}}} + \underset{\text{(Hypersthene.)}}{y\mathrm{MgSiO_3}}$$

The normal pyroxenes of igneous rocks of basic composition can be represented by various mixtures of the ferromagnesian silicate molecules, $CaMgFeSi_2O_6$, and $MgFeAl_2SiO_6$; and further, as Sir Jethro Teall[1] and W. Wahl[2] have shown, the molecule $MgSiO_3$

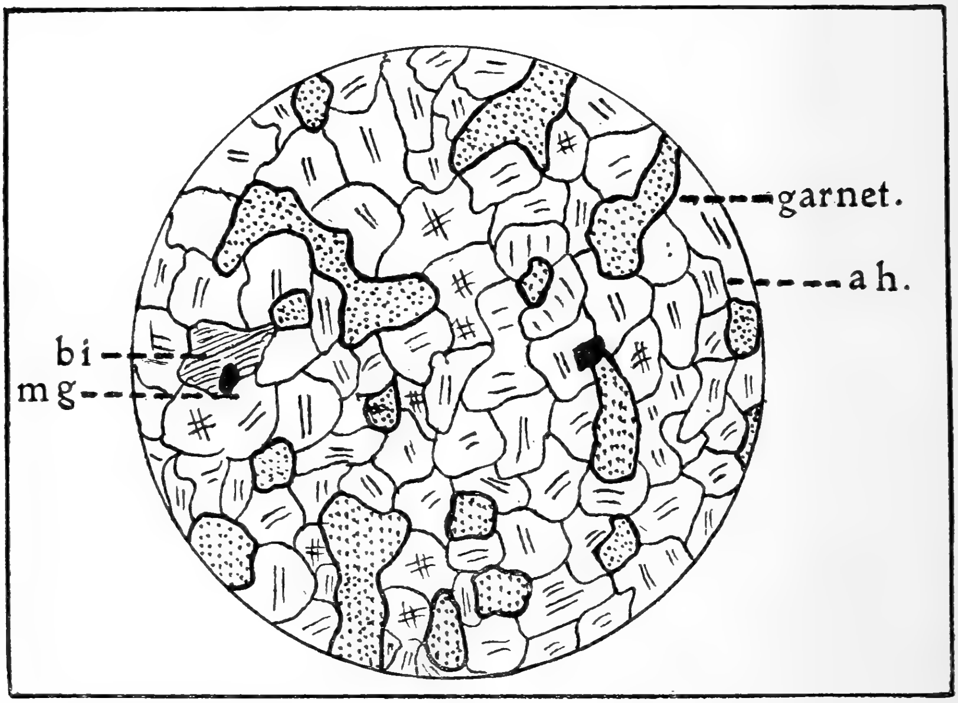
[1] Q. J. G. S. vol. xl (1884) p. 640.
[2] Min. Petr. Mitth. vol. xxvi (1907) pp. 1–131.

may enter in varying proportions. A recent analysis, by Dr. H. S. Washington,[1] of the augite of the Stromboli basalt shows that it consists of the following groupings:—

$$\begin{aligned} CaMgFeSi_2O_6 &= 80{\cdot}12 \\ MgFeSiO_3 &= 7{\cdot}48 \\ MgFeAl_2SiO_6 &= 7{\cdot}03 \\ NaFeSi_2O_6 &= 5{\cdot}46 \end{aligned}$$

This is perhaps a less aluminous type than is usual in rocks of basaltic composition, as many doleritic augites show an alumina percentage reaching or exceeding 6 to 7. The entry of the magnesium metasilicate molecule in large amount into the augite

Fig. 11.—*A pyroxene-garnet aggregate.* × *125.*



[ah=secondary augite and hypersthene; bi=biotite; mg=magnetite.]

constitution has been shown by Wahl to be accompanied by a marked change in the optical properties—notably a decrease in the optic axial angle, so that with a certain composition the pyroxene becomes uniaxial.

Among the 'relict' pyroxenes of the Lincoln dolerites are types with a low optic axial angle, some approaching uniaxiality; and the resemblance to members of the enstatite-augite group is further manifest in the presence in some of these of a salite striation. This influence of the $MgSiO_3$ molecule is to be suspected, when the

[1] Amer. Journ. Sci. ser. 4, vol. xlv (1918) p. 463.

rhombic silicate is found among the dissociation-products of the original pyroxene.

The associations of biotite and hornblende around the grains of iron-ore are also to be attributed to metamorphism, and perhaps are developments of a declining stage of this influence. The iron-ore has supplied a portion at least of the iron in the development of biotite, and the supply of potash is presumably derived from the felspar, small amounts of the orthoclase molecule usually being present in the constitution of the plagioclases. In the absence of exact knowledge of the agents by which this change is brought about, it is difficult to represent this biotite development by any trustworthy equation.

As to the origin and relationships of these metamorphosed dolerites, it is unfortunately difficult to say much. At Kirton Point, the dolerite is developed interbanded with the augen-gneisses. This band runs parallel with the primary foliation of the gneisses. At Boston Island, the orientation of these bands is not so constant, and in some cases there is a slight departure from a parallel orientation.

In none of these cases has a band been seen to send intrusive venules into the enclosing gneiss, nor, on the other hand, are the bands traversed by gneissic veins, as is so commonly the case with the neighbouring amphibolites. A massive structure of the dolerite might, however, account for such inaction. At first sight, these rocks appear to be characteristic dyke-rocks cutting the acid gneisses. When, however, the high-grade metamorphism is established, this opinion must be considered open to doubt.

The microscopic characters resemble in many particulars those of the basalt-lavas of Skye, which, becoming entangled as inclusions in the later gabbros, have been recrystallized, with development of secondary granulitic augite.[1]

The production of secondary augite as a result of a high-grade thermal metamorphism, has been recorded by Dr. W. F. Smeeth for the Kola schists of Mysore State, where they have been invaded by later granites.[2] He believes, however, that the secondary augite is here developed by recrystallization of hornblende of the pre-existing hornblende-schists. A somewhat similar type of metamorphism is presented by certain of the Lizard hornblende-schists. The occurrence of secondary augite in members of the Landewednack schists is ascribed to thermo-metamorphism of these rocks by intrusive masses of serpentine.[3]

Augite is thus a typical metamorphic mineral of the highest grades of metamorphism in rocks of this class. The possibility,

[1] A. Harker, 'Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, pp. 53 & 116.

[2] W. F. Smeeth, 'The Occurrence of Secondary Augite in the Kola Schists' Mysore Geol. Dep. Bull. 3 (1905) pp. 1–84.

[3] J. S. Flett, 'The Geology of the Lizard & Meneage' Mem. Geol. Surv. 1912, pp. 46–50.

therefore, that these bands of the Lincoln area may represent dolerites of anterior origin which have become engulfed and entangled in the acid gneisses, suffering at the same time an intense thermal metamorphism, must in the present state of knowledge not be excluded.

On the other hand, rocks bearing a remarkable resemblance to those which are under discussion have been quite recently described in detail by Dr. F. L. Stillwell from Adélie Land (Antarctica).[1] This author is able to produce indisputable evidence that the metamorphosed dolerites are a series of dyke-rocks in that they definitely ramify throughout the enclosing rock, and further that the enclosing rock itself is a metamorphosed sediment. Thus at Cape Gray, these dykes invade a rock which is now a garnet-cordierite gneiss, of the sedimentary origin of which there can be little doubt. The metamorphism of the whole series is ascribed to the conditions prevailing in Grubenmann's 'kata-zone.'

As against a dyke origin for the Lincoln rocks, it can be definitely stated that the enclosing rocks (the acid gneisses) owe their gneissic foliation to the stages of consolidation, and are essentially primary gneisses. There are no notable features in these rocks that can be assigned to any high-grade metamorphism. To whatever origin these dolerites can be ultimately ascribed, the essential conditions for their metamorphic features have been high temperatures and an uniform pressure, to the exclusion of any important shearing-stress.

The balance of evidence, and, for a posterior dyke-origin, the necessity of adducing a period of high-grade metamorphism, subsequent to the consolidation of the igneous gneisses, for which there is no other evidence, are in favour of the view that these dolerites (like the amphibolites with which they are associated) are inclusions derived from a pre-existing rock-mass entangled in, and thermally metamorphosed by, succeeding acid gneisses.

The close similarity of the metamorphosed Lincoln dolerites with the Adélie Land series may here be further remarked. The same 'relict' dusty pyroxenes are again observed, as also the granulitic secondary pyroxene. It is of further interest to note that Dr. Stillwell also records hypersthene as a dissociation-product of the primary augite. As he remarks, the resultant secondary pyroxene is thus more aluminous. The production of garnet is also observed; but the formation of this is ascribed to the felspar-pyroxene interaction. From the descriptions it would, however, appear that quartz is not always present as an associate of the garnet. If, as in the Lincoln rocks, garnet has been produced by an intramolecular change of the primary pyroxene, the resultant secondary augite is of necessity nearer diopside in composition, and this is probably the case even when hypersthene is a further product of this augite transformation.

[1] 'The Metamorphic Rocks of Adélie Land' Sci. Rep. Austr. Antarctic Exped. ser. A, vol. iii, pt. 1, sect. 1 (1918) p. 169.

Dr. Stillwell further describes types in which the pyroxenes become partly replaced by hornblende, and these present many features in common with No. 89 of the Lincoln Series.

No olivine has been recorded from these Antarctic dolerites, and no appeal has been made to an olivine-felspar interaction for the synthesis of garnet.

As presenting features intermediate between the metamorphosed dolerites and the pyroxene-amphibolites already described, several basic bands of which hornblende is an important constituent, from Boston Island and the coast immediately south of Tumby Bay, call for description. The constituents are hornblende, plagioclase, granulitic augite, and hypersthene, with minor and varying amounts of quartz, orthoclase, apatite, and iron-ores. A foliated structure may be imparted by a rude parallelism of hornblende; but, on the other hand, granoblastic textures are common. The original igneous character of these rocks is indicated by the presence of occasional blastophenocrysts of felspar, or blastoglomeroporphyritic aggregates of the same mineral.

No original augite is present, the pyroxenes being of the granulitic secondary type. Much of the hornblende can be regarded as derived from pyroxenes *in situ*, but there is also represented a type which by its shape and attitude must have been crystallized as such.

As seen in the field, these rocks preserve quite well-defined boundaries with the enclosing gneisses. Several junctions have been studied microscopically.

The gneiss at the junction shows a granulitic texture, with occasional phenocrysts of orthoclase and plagioclase, which may be aggregated at the border-line. The component minerals are quartz, orthoclase, plagioclase, and grains of hypersthene. The attitude of these pyroxene grains is noteworthy: along the border of the basic band is a concentration of the pyroxenic grains, and enclosed within the gneiss are aggregates and isolated grains of the same mineral. These show all the characters of being mechanically derivable from the basic band, representing xenoliths broken off the basic rock. If we accept this view, the metamorphism has been accomplished as a thermal effect of intrusion, and the secondary granulitic pyroxenes observed near the junction of the basic rock with the gneiss represent a derivation from the basic band itself.

IX. Comparison of the Flinders Series with the Rocks of other Pre-Cambrian Areas.

In drawing attention to features displayed in other Pre-Cambrian tracts—of similar type to those met with in the Flinders gneisses of Southern Eyre Peninsula, it will suffice to remark on a number of areas in the Northern Hemisphere.

(1) St. Lawrence County (New York).—C. H. Smyth,[1] in a short report on the crystalline rocks of this county, describes a series of gneisses associated with metamorphic limestones. The special point on which remark is necessary, is the relationship of certain basic bands in the igneous gneisses. These present features which are closely similar to those of the Flinders Series. In referring to the relations of the gneisses to the intercalated bands, Smyth remarks (p. 491):

'The possibility of the black bands being segregations in an igneous rock, is for the typical cases excluded by their form, although it may be applicable to some occurrences. There remains the supposition that the black bands are fragments of an older gneiss included in a gneiss of igneous origin..... the bands owe their shape to their breaking from the parent mass, as they would in the direction of least resistance..... The parallel arrangement of the neighbouring bands doubtless results from currents in the molten magma, which would tend to produce such a result. It is probable that the breaking into blocks resulted in part from stresses applied after the magma was in a pasty and partially crystallized state. The blocks were more or less widely separated and the intervening space was filled by the magma which flowed around the blocks without destroying their angular contour, and at the same time often produced an obscure flow-structure in the gneiss parallel to the sides of the inclusions.

'The fine fissures and cracks were filled with the more acid portions of the magma, which were last to crystallize, and were strained into these cracks producing the coarser pegmatitic veins.'

A consideration of the foregoing passages and of other facts which are adduced in the original paper, suggests that there is a remarkable resemblance between the relations of the basic bands and the enveloping gneisses for the two areas.

It is, however, not only in the New York region that parallels can be discovered for the features expressed in the Flinders gneisses. The work of Prof. F. D. Adams & Mr. A. E. Barlow in the Haliburton-Bancroft area of Ontario,[2] has shown that there is in this Laurentian tract a widespread development of basic amphibolitic bands within the granite-gneisses, exhibiting relations identical with those seen in the amphibolites of the Eyrian region.

(2) The Haliburton-Bancroft area (Ontario).—It is perhaps this region that bears the closest analogy in the structural composition and petrographical character of its Pre-Cambrian rocks to the Eyrian Pre-Cambrian. The oldest rocks of the area, the Grenville Series, afford a comparison with the Hutchison Series. Carbonate sediments now highly metamorphosed and paragarnet-gneisses of quartzitic and shaly composition are common to both series. In the succeeding Laurentian System, the gneisses with primary flow-structure, and their included amphibolite-bands, find parallels in the Flinders Series of gneisses.

Adams & Barlow have recognized amphibolites arising in more

[1] New York State Mus. Report 49 (1895) pp. 481–97.

[2] Mem. Geol. Surv. Canada, No. 6, 1910.

than one way, both from igneous rocks and from sediments, particularly from impure carbonate-rocks. In the Flinders Series there are no amphibolites that can be recognized as arising in the second way, nor in the associated Hutchison Series is such a process of development met with. They appear to be essentially of the first class.

The development of the older Hutchison Series in Southern Eyre Peninsula is in a more fragmentary state of preservation than the corresponding Grenville Series of Ontario. That series is penetrated by basic dykes and sills, now highly metamorphosed, and the igneous amphibolite-inclusions of the granite-gneisses are regarded as due to the shattering and rifting-off of these rocks from the invaded sedimentary series.

In the absence of any extended exposures of the Hutchison Series such processes cannot be observed in general in the Flinders area. We have, however, already noted the presence of definite inclusions of sedimentary rock of dolomitic origin, in the diopside-bands developed in the gneisses of Sleaford.

The field-evidence encourages the interpretation of the amphibolites as pre-existing igneous rocks which have become involved in the later gneisses, these igneous rocks in all probability having been intruded into—and there consolidated—a portion of the crust corresponding to an extension of the present fragmentary Hutchison Series, or some earlier formation, at a period preceding the irruption of the granite-gneisses.

(3) The Lewisian area of the North-West Highlands of Scotland.—In the Lewisian tract, with its great development of basic bands alternating with more acid and granitic types, a parallel with the Eyrian region is again revealed. There appear, however, to be certain distinctions forbidding that close comparison which I have instituted with the Ontarian region.

The relations of the gneisses and their intercalated basic bands in the Lewisian tract (as described in the Survey memoirs) are of a much more complex and involved nature than in the relatively simple Laurentian and Eyrian areas. It would appear that hybridism has played a much more important part, and the distinction between basic and acid members is less sharply demarcated.

The vivid analogy which Sir Jethro Teall [1] has drawn between the relations of these basic and acid portions of the complex, and the forms and dispositions of the foam-flecks on the pools of comparatively still water below falls and rapids, also the intensive disruption with concomitant hybridism of the earlier basic members, have—with the exceptions of highly-localized areas—no parallel in the Eyrian region.

[1] 'The Geological Structure of the North-West Highlands' Mem. Geol. Surv. 1907, p. 71.

With regard to this Lewisian area, Sir Jethro Teall & Sir Archibald Geikie,[1] and later Dr. A. Harker,[2] have drawn attention to the features developed in the Tertiary gneisses of Skye and Rum, where in the first-named heterogeneity has arisen from imperfect differentiation, and in the second masses of gabbro have been involved in the succeeding acid granites. Such processes as are revealed in these Tertiary gneisses, where the history of the rocks can be studied more accurately, must be of fruitful application in those older formations where only the latest stages of reaction and interaction are the visible remnants from which conclusions must be drawn. The sequence of events as disclosed in the history of the much younger plutonic activity, adds confirmation to the view, that in the basic members of Archæan gneissic tracts the widespread disruption of an earlier consolidated phase (probably of the same plutonic cycle) is laid bare. An interpretation of the distinction between the Lewisian tract on the one hand and the Ontarian (and we may perhaps add the Eyrian) region on the other; the more complex intermingling of basic and acid members; and the resultant hybridism already remarked in the Lewisian Series, may be afforded by the great dominance of the element of powerful lateral pressure accompanying the Lewisian irruptions, and the intrusion of the Ontarian and Eyrian granites under the influence of much simpler mechanical forces.

It may be asked, however, how far these distinctions are a function of the depth of erosion of the particular region, whether with increasingly lower levels of such a formation exposed to view, an increasingly more complex intermingling of earlier and later members, and a greater degree of hybridism, stand revealed?

X. Bibliography and Summary.

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Id. Geol. Mag. 1921, p. 251.

Id. 'Economic Geology,' 1921, pp. 184–98.

(1) Granites and granite-gneisses of Pre-Cambrian age occupy a large portion of the south-eastern tract of Eyre Peninsula. These gneisses were intruded into an older series of rocks, the Hutchison Series, only remnants of which are now exposed.

(2) The petrography of the gneisses and their satellitic pegmatites and aplites is described. They include biotite, hornblende-biotite, and hornblendic granite-gneisses, pyroxene-

[1] Q. J. G. S. vol. l (1894) pp. 645–59.
[2] *Ibid.* vol. lix (1903) pp. 207 *et seqq.*

granites of the charnockite-type, and a great development of garnet-gneisses. The pegmatites are predominantly hornblendic types, with diopside as an occasional constituent.

(3) The gneissic structure developed in these rocks is a primary gneissic banding arising from flow-movements in a heterogeneous magma. The nature of the heterogeneous magma, and the conditions under which a foliation and banding are developed are discussed.

(4) Included within the granite-gneisses, and alternating with them, is a series of amphibolite-bands oriented in parallel. They include amphibolites proper, pyroxene-amphibolites, pyroxene-granulites, and quartz-orthoclase amphibolites. These amphibolites are of anterior origin with respect to the acid gneisses, and I give a description of the evidence on which this conclusion is based.

(5) In addition, there are fragments of highly metamorphosed sediments, identical with members of the earlier Hutchison Series, enclosed within the acid gneisses. These include diopside-rocks, garnet-biotite schists, and xenoliths of garnet- and green spinel-sillimanite type.

(6) The amphibolites have the mineralogical composition of basic igneous rocks. In the case of the quartz-orthoclase bearing types, an analysis shows a close resemblance to certain quartz-gabbros. This is further confirmed by the presence of an amphibolite-band, of the composition of a micropegmatitic dolerite at its centre, passing into a normal quartz-bearing amphibolite at the periphery.

The metamorphism and the origin of these rocks are discussed. They represent earlier consolidated rocks which have become involved and engulfed in the later acid gneisses.

Some posterior dykes of basic charnockitic composition cut the acid gneisses, at various localities.

(7) Of more than ordinary interest are certain bands of doleritic type, which are intercalated in the gneisses of Kirton Point and Boston Island. These appear to have experienced a metamorphism of the highest grade. The pyroxenes have been recrystallized, and garnet abundantly formed. Hypersthene and garnet have arisen in part as a result of a degradation of a complex pyroxene molecule. The nature of the chemical changes induced by this high-grade metamorphism is discussed.

It seems probable that these dolerites are earlier rocks, engulfed and thermally metamorphosed by the granitic magma.

(8) A comparison of the Eyre Pre-Cambrian tract with Archæan tracts of the Northern Hemisphere is instituted. In structural composition and petrographical character, the Eyre region bears a striking resemblance to the Laurentian tract of North America, and particularly to the Haliburton-Bancroft area of Ontario.

Discussion.

Dr. A. Wade congratulated the Author upon the thorough piece of work which he had presented. He had spent some time in mapping the area in connexion with a report on petroleum resources for the South Australian Government.

The speaker drew attention to the difficulties under which the Author must have laboured while engaged on this work. There was great need for further research of this character in South Australia. He quoted, for example, a dome-like mass of granite surrounded by a variety of metamorphosed sedimentaries near 'The Frenchman,' on the western coast of Eyre Peninsula, as also the granites of the southern coast of Kangaroo Island which have broken through and engulfed sedimentary rocks, included portions of which are to be seen in all stages of assimilation and alteration. The speaker could confirm many of the Author's observations, and was in entire agreement with him as to the age of the gneisses and associated rocks.

Mr. J. F. N. Green appreciated the close and restrained reasoning of the paper, based on careful observation. He was not sure that the same epithets could be applied to other reasoning that had recently come from South Australia, and could not agree that Mr. Stillwell had definitely proved a dyke origin for the Adélie-Land amphibolites. The Eyre district did not seem to compare well with Haliburton, where there was a special association of rocks, notably oligoclase-gneisses, varied alkali-syenites, and scapolite-amphibolites, which was repeated with detailed resemblances in other places, such as the Urals and the Gold Coast; rather it followed the commoner type found south of Haliburton, where gneisses carrying more basic felspars broke up the Keewatin lavas at the base of the Ontario Archæan series. The occasional preservation of amygdales and 'pillows' left no doubt that the Keewatin basic rocks had been lavas.

This valuable paper added to the growing volume of evidence that orthogneisses were usually not, properly speaking, metamorphic at all, but in their original state of consolidation; and that the chief element in the metamorphism surrounding them was thermal. The drawing of foliation-planes of gneiss curving with the edges of twisted amphibolite was especially interesting, and might be compared with maps on a much larger scale, as, for instance, in the metamorphic areas of New York State; but it should be remembered that the most striking evidence for this view, stronger even than that collected in North America, was laid before the Society twenty-seven years ago by Mr. G. Barrow.

Mr. G. H. Plymen said that a study of the Pre-Cambrian rocks of the Channel Islands enabled him to appreciate the value of the Author's work. The invasion at Port Lincoln of hornblendites by a gneissose rock closely resembled the banded gneisses and hornblende-schists of Sark. In Port du Moulin (Sark) the latter name was applied to the finer bands and the former to the coarser

bands, but both were part of one mixing, apparently 'sheared.' At Castle Cornet (Guernsey) fine interbanding of gneiss with aplite was traversed by residual aplite across fractures of the structure such as the Author described. The mixing of aplites and granites, or of aplites and more basic matter, was again similar at Elizabeth Castle (Jersey) and at Ronez; but here the shearing was absent.

There were no garnet-rocks in the Channel Islands, which might be explained by the moderate amount of biotite and the comparative absence of augite. The speaker wished to know whether the Eyre Peninsula produced evidence of 'banded diabase' with long hornblendes developed in the parting planes by pressure, as seen in the east of Guernsey.

Mr. W. Campbell Smith asked the Author whether the hornblende-pegmatites were always associated with included patches of the amphibolite series in the granite-gneiss. Mr. F. Debenham had mapped an area of biotite-granite in South Victoria Land, in which included patches of para-pyroxene-granulites were always surrounded by hornblende-granite of a peculiar type. The suggestion, not yet worked out, was that the hornblendic facies was the result of absorption of the pyroxene-granulite by the biotite-granite. He was disappointed to learn that the Author considered that myrmekite could be formed during the final stages of consolidation of granite, and that it was not peculiar to gneisses. With regard to a previous speaker's remarks on Stillwell's basic rocks, he was inclined to think that a fair case had in fact been made out for their being dyke-rocks. The rocks of Adélie Land and those now described showed many points of resemblance. It would be interesting to hear the Author's opinion of Stillwell's work in this connexion.

Dr. J. W. Evans remarked on the similarity of the rock-types described by the Author to those of Peninsular India. He believed that rocks of charnockitic type owed the presence of orthorhombic pyroxene to the absorption of argillaceous strata, resulting in the presence of a considerable amount of alumina which, in combination with silica, used up all the lime in the formation of anorthite in plagioclase, leaving none for diopside.

The Author stated, in reply to Dr. Wade, that the rocks of Western Eyre Peninsula were petrographically distinct from the series now dealt with, and constituted in fact a new series in the Pre-Cambrian sequence.

He stated, in reply to Mr. J. F. N. Green, that the parallel which had been drawn with the Laurentian tract of Ontario applied, not only to the gneisses themselves, but to the pre-existing sediments now highly metamorphosed. With regard to the relationships of the associated amphibolites, he knew of no closer parallel than the example which the Ontarian region afforded.

No 'banded diabases' of the nature described by Mr. Plymen had been met with in the area investigated.

In reply to Mr. Campbell Smith, he said that the hornblende-

pegmatites, while often associated with the amphibolites, also occurred as distinct dykes cutting the Flinders gneisses. With regard to myrmekite, this structure was also developed in certain Palæozoic intrusions (for instance, in the Caledonian granites of Galloway). Its comparative rarity in later granites and abundant development in Pre-Cambrian granites might be attributed—not to metamorphism, but to the intrusion of the Pre-Cambrian granites in regions of comparatively less steep temperature-gradients, with the result that the final residual solutions could act for longer periods on the already crystallized minerals.

In reply to Dr. Evans, the Author stated that there was no evidence in the area in question, that assimilation could account for any of the features shown by the pyroxene-granites. He regarded the development of pyroxene as a resultant of a comparative poorness of magmatic water, whereby the metasilicate molecule did not suffer degradation to the orthosilicate type of the micas. He had not found any perthitic intergrowths in these rocks, in which the plagioclase was as calcic as andesine.

6. *The* Surface *of the* Marls *of the* Middle Chalk *in the* Somme Valley *and the* Neighbouring Districts *of* Northern France, *and the* Effect *on the* Hydrology. By William Bernard Robinson King, O.B.E., M.A., F.G.S. (Read March 9th, 1921.)

[Plate III—Map.]

The folds of the Mesozoic and Tertiary rocks of Northern France have been studied by various geologists in the past, notably E. Hébert, M. Bertrand, J. Gosselet, L. Cayeux, G. F. Dollfus, and H. Parent.

Theoretical considerations regarding the relationship of the later folds to the older pre-existing folding have led some of these geologists to study this problem, while others have endeavoured to trace some connexion between the tectonic structure and the development of the river-systems. In these pages, however, I propose to set forth certain information derived from the records of the boreholes which were made by the British armies during the War, and to draw some conclusions regarding the relationship between the tectonic features and the hydrology.

During the War the geological work in connexion with water-supply fell into two main groups—(1) the endeavour to furnish details of the strata in the area occupied by the British armies, together with notes on their water-bearing capacity; and (2) the preparation of notes on areas over which an advance might take place.

In connexion with the first of these requirements, much useful information was obtained from the late Prof. J. Gosselet's works, particularly his maps of the contours of various horizons,[1] which proved of great use in estimating the depth at which various strata occur.

The area under consideration (see map, Pl. III) consists fundamentally of Cretaceous deposits, but frequently has a superficial covering of Quaternary loams, Clay-with-Flints, and small outliers of the basal Tertiary clays and sands. From the point of view of water-supply from boreholes only two members of the Cretaceous System need be considered: namely, the Turonian and the Senonian.

In the eastern parts of the area there are two markedly-different lithological types. The Lower and Middle Turonian (zones of *Inoceramus labiatus* and *Terebratulina gracilis*) are grey-blue

[1] 'Études des Gîtes Minéraux de la France—Les Assises Crétaciques & Tertiaires dans les Fosses et les Sondages du Nord de la France' Paris, 1904–1913.

clayey marls, practically impervious to water; while the Upper Turonian (*Holaster-planus* Zone) and the Senonian are made up of porous flint-bearing chalk.

In the lower beds, water only circulates in occasional joints, while in the upper group the whole mass is extremely porous, and the water has a free circulation. If, however, the beds be traced towards the west, the clayey nature of the *Terebratulina-gracilis* Beds is gradually lost, and the marls are confined to the Lower Turonian and the Cenomanian; but the *T.-gracilis* Beds remain practically free from flints, and the *Holaster-planus* Zone still coincides more or less with the appearance of flint-bands and flint-nodules in abundance.

Since the marls of the Middle Chalk have a certain controlling effect upon the behaviour of the underground water (and also on the surface-water), it was important (1) to ascertain the amount of this controlling effect, and (2) if that proved to be of sufficient consequence, to devise some plan whereby the information could be put in a readily accessible form for the use of the water-supply officers in the armies.

To the first of these points I shall return later; for the second, a map of the contours of the summit of the marls (that is, the top of the *Terebratulina-gracilis* Zone) was constructed from the evidence of the boreholes, which already existed—either French (where records are available), or British Army borings up to date. Where the marls cropped out at the surface, the altitude of the outcrop of the highest bed was taken from the French geological maps.

A map, similar to those constructed by Prof. Gosselet (*op. jam cit.*), was thus plotted out. This enabled an estimate of the depth to the marls at any point to be arrived at with ease, by subtracting the figure obtained from this map from the surface-altitude as shown by the contours of the topographical maps.

As new records came to hand, the curves needed some modification, in order that they might be brought into line with the new information. Pl. III is taken from the final map, after records of all the boreholes had been received and the necessary corrections made. On this map was entered the position and altitude of the marls in each borehole made by the six water-boring sections which were part of the water-supply organization of the British armies in France.

Each of these water-boring sections was under the command of an engineer officer possessed of the technical knowledge necessary to direct the boring work. One of his duties was to enter on a form all details available regarding the strata through which the bore passed, the yield of the bore, together with particulars of the casing which had been installed by the Boring Section, the location of the site, and similar information. These forms were sent to the water-supply officer, and a copy was forwarded by him, in due course, to the Engineer-in-Chief's office at G.H.Q. Here the information was condensed and entered on cards which were

arranged in card-catalogue form, under place-names, so that any record could be easily accessible when needed.[1]

Unfortunately, the method of drilling and the nature of the rock made it extremely difficult to determine with any degree of accuracy the exact position of the top of the 'Marls' in any bore. Percussion-drilling was the method always used, so that the change from Upper White Chalk to the bluish marls of the Middle Chalk could only be detected by the colour of the sludge or by small fragments adhering to the end of the chisel. The driller, also, had some indication of the change to the marls by the way in which the chisel was gripped more firmly by the stiffer marls than by the more friable chalk. It was, therefore, often a matter of considerable doubt as to where, within 5 or even 10 metres (say, 16½ or 33 feet), the line of the top of the marls should be drawn. The presence or absence of flints was a good indication; but frequently fragments of flint were knocked off the side of the bore where it was in the Senonian, and these flint-fragments were pounded into the marls by the chisel, and thus were brought up mixed with the marl. This gave rise to the frequent entry of 'Marl with flint' on the part of the driller.

Another and important source of error in the figures on the map arose from the inaccuracy of the contour-lines on some of the maps, and also from the uncertainty of the exact position of the boring where the map-location had not been given in sufficient detail.

It will be seen from the foregoing observations that frequent and often considerable errors are to be expected in a map constructed from such data, but the great number of borings helps to reduce the errors in the curves, and the map thus made brings out several points of interest.

If we study now the form of the surface of the marls as shown on Pl. III, the general lines are seen to be very similar to those of the surface of the Chalk given by M. G. F. Dollfus.[2] The chief differences are that, while this map shows all post-Turonian deformations, M. Dollfus's map indicates only the post-basal Eocene folding.

The general scheme of folding shows, in the west, a series of anticlines and synclines, somewhat irregular in their amplitude, but with a definite north-west and south-east strike; while in the eastern part there is a central broad anticlinal ridge, with a strike changing from north-west and south-east to east-north-east and west-south-west on the extreme eastern margin of the map. In the north-eastern corner is a well-marked basin, and in the south a low irregular dome.

If we examine the map in detail from south to north, the first feature that leaps to our eyes is the syncline of the Somme.

[1] A catalogue of the bores, together with tabulated details of the thickness of the various strata, has been published by the Société Géologique du Nord, Ann. Soc. Géol. Nord, vol. xlv (1920) pp. 9–34 & map pl. i.

[2] Bull. Serv. Carte Géol. France, No. 14, vol. ii (1890–91) pp. 1–68 & map; map reproduced in Proc. Geol. Assoc. vol. xxi (1910) pl. v.

The centre of the fold, however, does not appear to coincide with the present line of the River Somme, but to lie a few miles south of that river. The bifurcation of the syncline at Amiens is clearly seen, the main axis following the line of the Avre; and a distinct synclinal line is seen coinciding with the Somme river from Amiens to Péronne. The southern side of this syncline is formed by the dome-like elevation indicated by the borings of Assevillers, Rosières, etc. (over 40 metres above sea-level); while all borings in this reach of the Somme Valley find the marls below sea-level. This dome, then, is the slight secondary anticlinal axis suspected by M. Dollfus.[1]

North of the river the contour-lines rise to a crest, which runs in a sweeping curve from Le Cateau through Le Catelet and Nurlu to Flers. Before the line of the Ancre this crest appears to become somewhat indistinct; but a strong anticlinal ridge replaces it en échelon on the line Bihucourt–Saulty, while farther west a second dome on the line Valheureux–Bernaville appears between the syncline of the Somme and that of the Authie.

North of the Le Cateau–Flers and Bihucourt–Saulty ridges the contours fall to the great depression of Douai and the basin of Orchies, and to the synclinal axis which runs somewhat south of the main road from Arras to St. Pol. Still farther north the curves rise again to the high ground of the Vimy and Notre Dame-de-Lorette ridges, which coincide with the maximum elevation of the marls (over 175 metres above sea-level) before they are brought down about 100 metres (328 feet) by the great fault and fold of Marqueffles, to fall gradually under the Tertiary covering of the plain of Flanders.

This series of contour-lines indicates, therefore, in a general way the amount and position of the deformation which has taken place since the Turonian marls were deposited: the assumption being that the sea-bottom at the time of deposition was horizontal.

The folds are seen to trend in a north-west and a south-east direction in the west of the area; but they gradually swing round to an east-and-west line, and finally, on the eastern edge of the map, they are trending east-north-east and west-south-west. The reason for this change in strike is discussed later.

Another point of considerable interest is that, when the line of maximum elevation of the marls is traced from east to west, we find that it is not a continuous curving line, but a series of short curves arranged en échelon, resulting in a stepping of the crest-line gradually farther and farther northwards.

Thus, in the east, the main crest-line is on the line Le Cateau–and Le Catelet–Nurlu, gradually falling from over 100 metres (328 feet) at Le Cateau to less than 75 metres (246 feet) on the line of the Tortille River, with some slight indication of the continuation of this line westwards, as proved by the borings at Flers

[1] *Op. cit.* p. 45.

and Pozières. This line is the old axis of Artois, as shown on Prof. L. Cayeux's map.[1]

If the curves now plotted out are approximately correct, it will be seen that the maximum crest-line does not swing round by Bapaume and Bihucourt to Saulty; but rather that the whole area between the valleys of the Tortille and Hirondelle on the east and those of the Ancre and Sensée on the west is a region of low altitude of the marls, where the main axis is lost in a slightly undulating low-lying plain, and that the main crest-line on the west of this area is on the line Bihucourt-Saulty: that is, about 7 miles north of the position where a continuation of the Le Cateau-Nurlu line would have been situated.

When the Bihucourt-Saulty line is traced westwards, a repetition of the same phenomena is observed. The anticlinal axis is lost in the great synclinal depression which runs from Hesdin to Arras. The borings in this area are, however, not numerous, and the marls are losing their extremely clayey nature, so that little information is available from a study of the evidence afforded by them. The map nevertheless clearly shows how the Bihucourt-Saulty line is lost in the west, and that the main crest-line is taken up in the north by the Vimy–Notre Dame-de-Lorette ridges.

M. H. Parent has studied the curves of the marls in the north of Artois,[2] and his map shows how the axes are not continuous, but are separated by north-and-south breaks, or what (from analogy with the Bapaume area) might be explained by the disappearance of an anticlinal ridge in an area of general low or high elevation, and the replacement of the axis, not necessarily on the same line, but more probably on a line situated somewhat *en échelon* to it. This arrangement of maximum crest-lines of the marl-surface is one that might be expected from general considerations of the underlying tectonic structure of the region.

Under the line of the Vimy and Notre Dame-de-Lorette ridges the Devonian grits are packed on top of the Carboniferous deposits, and in post-Cretaceous times folding and faulting has continued along this old line, causing the maximum elevations of the marls in this district. East of Arras, however, the great basin of Orchies appears to have subsided under the lateral pressure of the post-Cretaceous folding, and has thus given rise to the low area in the marl-surface south of it.

The manner in which the crest-line is formed by a series of curved axes arranged *en échelon* would also be the natural result of the folds accommodating themselves to the change in strike which takes place on this north-and-south line of weakness.

We may now turn to the question of the connexion between the

[1] 'Ondulations de la Craie de la Feuille de Cambrai, &c.' Ann. Soc. Géol. Nord, vol. xvii (1890) pp. 71–90 & map.

[2] 'Notes Supplémentaires sur les Plis du Nord de l'Artois' Ann. Soc. Géol. Nord, vol. xxi (1893) pp. 93–104 & pl. v.

tectonic structure and the hydrology, and consult the account given by Prof. L. Cayeux (*op. jam cit.*) of the country around Cambrai: in this he correlates practically every stream or dry stream-course with a tectonic fold. M. G. F. Dollfus,[1] however, argues that the numerous folds at right angles to the main axis are difficult of explanation, and he does not agree that there is likely to be any close connexion between the tectonic lines of the Cretaceous and the present-day river-system, since the latter originated on a Tertiary covering and is superimposed on the Chalk as at present exposed.

This may be the case, but it is probable that in this area the folding of the Tertiary beds was along the lines of the post-Cretaceous and pre-Tertiary folds, and that even if the folds did not absolutely coincide in the position of their axes, yet the general trend was probably the same. This may be the explanation of the lower valley of the Somme. From the map it is clear that the river flows about 4 miles north of the lowest point of the syncline, as indicated by the Cretaceous deposits. It may be that the river is on the axis of the syncline of the Tertiary rocks, which was situated north of, but parallel to, the old pre-Tertiary axis on the south.

Similarly, the upper Ternoise and upper Scarpe valleys do not appear to coincide with the syncline which runs from Hesdin to Arras, but the rivers are situated about 3 miles north of the Cretaceous tectonic axis.

The Somme from Amiens to Péronne is clearly influenced by the dome which splits the syncline of the Lower Somme into two parts, one being occupied by the Avre and the other by the Somme.

The sudden change of direction of the Somme at Péronne is more difficult to explain, unless it be due to a north-and-south fold; and in this connexion the fact that this stretch of the Somme is in line with the Tortille and that part of the Hirondelle stream which is followed by the Canal du Nord, must be of significance. It has been pointed out before that along this line the main axis from Le Cateau to Nurlu is lost in the broad, slightly undulating, low-lying area which is indicated by the altitudes of the marls.

Perhaps, also, the Ancre–Sensée line and Tortille–Hirondelle line are complementary one to the other at each side of the low area of the Somme battlefields.

The correspondence between the folds and the general parallel alignment of the rivers in their lower reaches is too well established to need comment here.

The relationship of the tectonics of the area to the capacity of the strata for yielding water in boreholes is a point of considerable

[1] Bull. Serv. Carte Géol. France, No. 14, vol. ii (1890–91) p. 54.

practical importance, and it was largely with this aspect of the subject in view that the work of tracing the folds of the Chalk was begun.

Since the diameter of the boreholes made by the British Army was either 6 or 8 inches, the results derived from a study of the yields of these bores may be valid only for small-diameter borings yielding a maximum flow of 12,000 gallons hourly.

The majority of the borings were sunk in areas where the clayey nature of the Middle Chalk marls was well developed. In districts where the marls actually cropped out at the surface, it was obviously of little use to bore for water, for the chance of striking a good water-yielding fissure was small. The same conditions, from a practical point of view, hold in those areas where the main Chalk water-table surface falls below the Senonian and *Holaster-planus* Chalk and enters the marls.

As evidence that this is actually the case, several borings which were situated in these areas, where the surface of the marls was above the water-table, may be quoted: namely, the boring on the Vimy ridge near Roclincourt, the Saulty boring, and some of the borings in the neighbourhood of Candas, etc. These borings yielded less than 1000 gallons hourly. The map of the marl-surface, together with details of the depth at which water is found, naturally gave useful information on this subject.

The converse generally, but not always, held good—namely, that in the synclinal areas, where the water-table was well up in the Senonian, all the borings yielded good supplies, from 6000 to 12,000 gallons hourly. This variation in yield could frequently be accounted for by the change in mechanical efficiency of the air-lift pump with the different ratios of lift to submergence in the various borings. The exceptions, however, are worthy of note, since they corroborate the results obtained in the areas where there were only a few feet (up to 50 feet) of water-bearing Chalk below the water-table.

In both these areas it was found that bores on the summits of hills (Gurlu Wood) or on the highest points of the plateau (Pozières No. 1, etc.) yielded very poor supplies; while borings within a few hundred yards in the heads of dry valleys yielded good supplies (Pozières No. 2, Orvillers, etc.). Perhaps the most noticeable example of a good yield in this zone, where the surface of the marls was almost coinciding with the water-table, was that of Bernaville; but this bore was situated at the bottom of a dry valley, situated some 400 yards back from the highest point of the plateau. Similar results were found at Fressonneville (west of Abbeville), where the boring on the top of the plateau proved a failure; but one in a dry valley, about half a mile from the crest of the plateau, yielded an excellent supply.

It was the exception to find that borings on the actual summit of the plateau yielded as well as borings situated a little down the dry valleys, regardless of the fact whether the area was synclinal or anticlinal in structure.

One case, however, of a good supply from a boring on the top of a hill occurred at Beaurains (south of Arras); but, as a general rule, the local topography of the district was a much greater controlling factor in determining the yield of a boring than the general tectonic structure, provided that the surface of the water-table was not less than about 50 feet above the surface of the marls.

In conclusion, I wish to acknowledge the liberal help and unfailing kindness which I always received while in France from Prof. (then Colonel) Sir T. W. Edgeworth David, K.B.E.

EXPLANATION OF PLATE III.

Sketch-map of the Somme Valley and neighbouring districts of Northern France, showing the contours of the surface of the marls of the Middle Chalk at intervals of 25 metres (82 feet), on the approximate scale of 8 miles to the inch or 1 : 506,880.

Discussion.

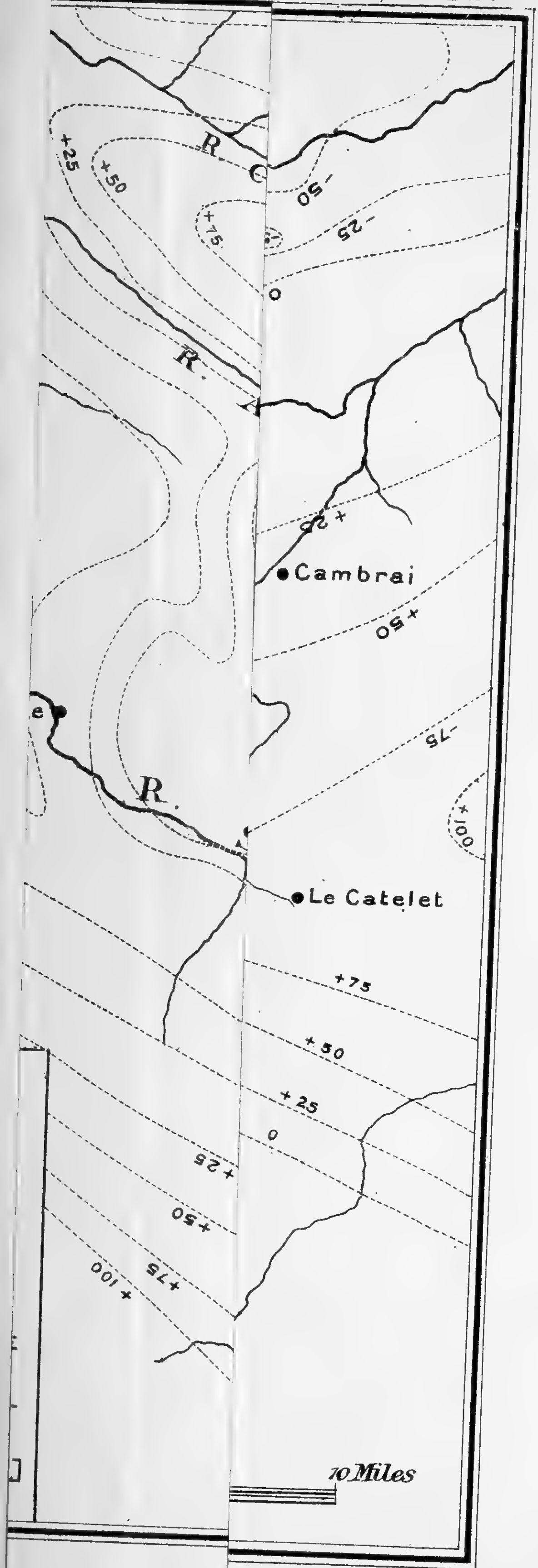
Prof. W. W. Watts noted that the Author had observed a definite relation between water-supply and surface-topography. Water-engineers had the habit of sinking wells in valleys, and the reason seemed to be that not only did water travel in Chalk along the fissures, but, moving in a definite direction towards any outlet, it in the end produced by solution a definite system of converging channels in that direction, which could be tapped by a well. The necessary outlet had often been produced by lowering of ground in the formation of the valley.

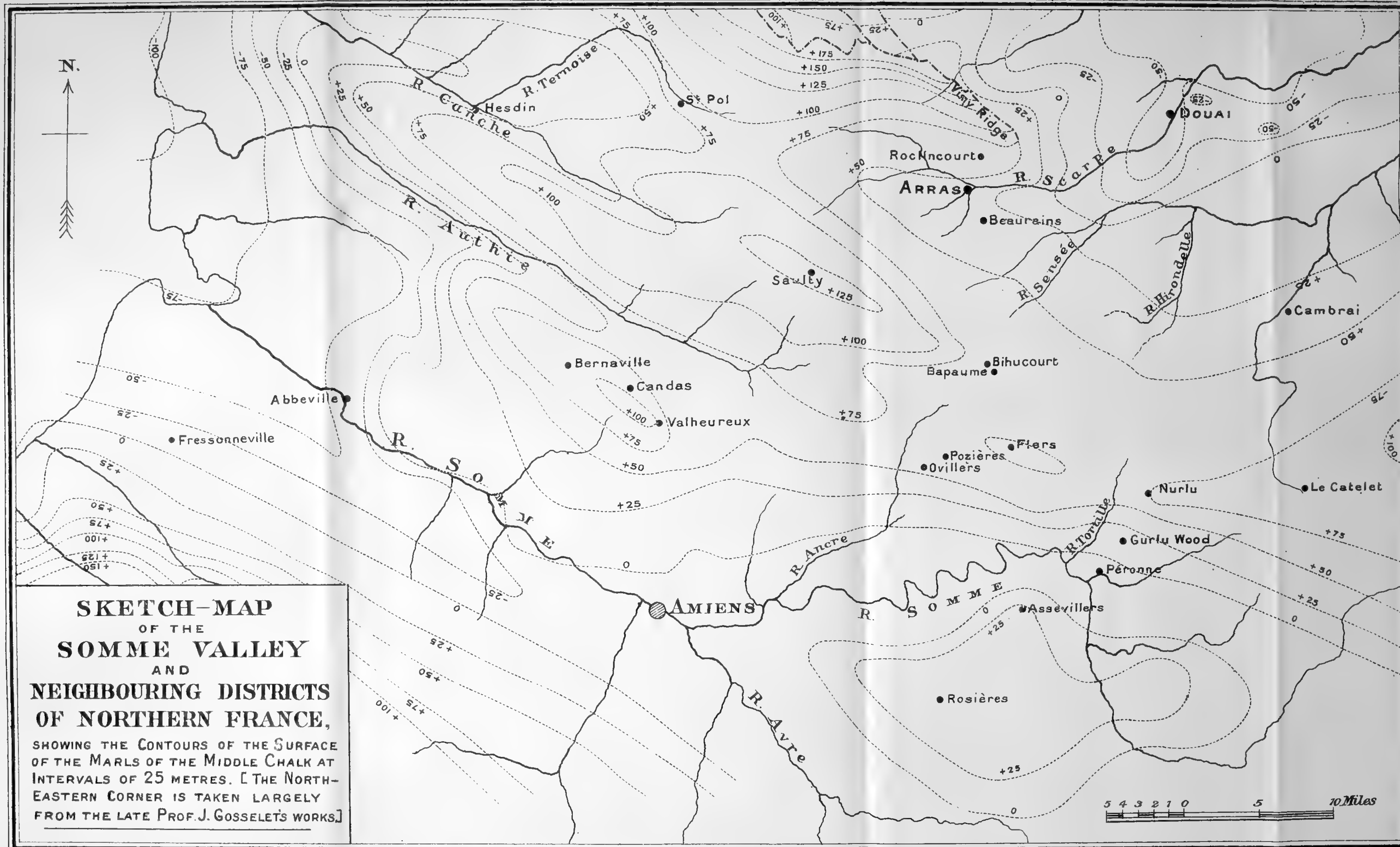
Prof. P. F. Kendall remarked that the Author's observations were of great interest and value. If the same type of structure extended to the Chalk between the Boulonnais and Calais, it would have to be taken carefully into account in laying out the line of the Channel Tunnel, otherwise, in view of the amplitude of the folds, it might be apprehended that the tunnel would need to be deflected in order to avoid passing into heavily-watered divisions of the Chalk.

He asked the Author to explain the sense in which he used the expression 'water coming out of the Chalk,' in contradistinction to that yielded by fissures. Though the Chalk is perhaps the most porous rock in the British sequence, having a porosity in some examples as high as 46 per cent., the water contained in the pores will not drain out to become available for the supply of wells or boreholes.

Dr. J. W. Evans suggested that the fact that the east-south-east and west-north-west streams were usually a little to the north-east of the parallel synclines might be accounted for by a dip of the axial planes of the folds to the south-south-west, as in

LXXVII, Pl. III.




SKETCH-MAP
OF THE
SOMME VALLEY
AND
NEIGHBOURING DISTRICTS
OF NORTHERN FRANCE,
SHOWING THE CONTOURS OF THE SURFACE OF THE MARLS OF THE MIDDLE CHALK AT INTERVALS OF 25 METRES. [THE NORTH-EASTERN CORNER IS TAKEN LARGELY FROM THE LATE PROF. J. GOSSELET'S WORKS.]
N.
Hesdin
R. Ternoise
St Pol
R. Canche
Vimy Ridge
Douai
Roclincourt
Arras
R. Scarpe
Beaurains
R. Authie
Saulty
R. Sensée
R. Hirondelle
Cambrai
Bernaville
Candas
Bapaume
Bihucourt
Abbeville
Valheureux
Fressonneville
Flers
Pozières
Ovillers
Nurlu
Le Catelet
R. Somme
R. Tortille
Gurlu Wood
Péronne
R. Ancre
Amiens
Assevillers
R. Avre
Rosières
5 4 3 2 1 0 5 10 Miles

North Devon. If this were the case, the position of the synclines at the surface anterior to denudation might well have coincided with the streams.

The AUTHOR said, in reply to Prof. Kendall, that he realized that Chalk yielded water only from small cracks and fissures, but these were so numerous in the Chalk (in comparison with those in the marls), that, while the one was impervious to water, the other behaved as a porous mass. In regard to the folds of the Chalk on any proposed site for the Channel Tunnel, it should be remembered that the majority of the borings were situated near the zone of fighting, and it was therefore lucky for us that the information was scanty in the Calais district.

In reply to Dr. Evans, the Author said that the suggestion which was made in the paper that the Tertiary syncline was actually situated north of the Cretaceous one was intended to account for the marked difference in the position as given by M. Dollfus and that shown by the recent borings.

7. THE VALENTIAN SERIES. By Prof. OWEN THOMAS JONES, M.A., D.Sc., F.G.S. (Read April 20th, 1921.)

CONTENTS.

I. HISTORY OF THE NOMENCLATURE OF THE VALENTIAN SERIES.

THE term is now commonly adopted for the rocks which lie between the top of the Bala and the base of the Wenlock or Salopian. These rocks have a wide distribution in Wales and the Borders, the Lake District, and the South of Scotland, as well as in Ireland and on the continent of Europe. They exhibit great diversity of lithological and faunal characters and of thickness when traced from one district to another, and on this account their classification and correlation has always presented difficulty. Various classifications are in current use, but their relation one to the other is still ambiguous. It is with the hope of clearing up some of these difficulties that the following account of the historical growth of the nomenclature and the correlation of the rocks has been written.

The earliest notice of these rocks in geological literature occurs in two early papers by Sir Roderick Murchison,[1] which were read to the Geological Society of London in 1833 and 1834.

In the earlier paper the rocks below the Old Red Sandstone in the western parts of Shropshire, Herefordshire, Radnorshire, Brecknockshire, and Carmarthenshire are arranged as follows, in descending order:—

1. Upper Ludlow Rock.
2. Wenlock Limestone.
3. Lower Ludlow Rock or Die Earth.
4. Shelly Sandstones.
5. Black Trilobitic Flagstone.
6. Red conglomerate, sandstone, and slaty schists.

[1] Proc. Geol. Soc. vol. i (1826–1833) p. 474 (read April 17th, 1833); and vol. ii (1833–1838) p. 13 (read January 22nd, 1834).

The Shelly Sandstones (No. 4) are those that rise at low angles from below the Lower Ludlow Rock in Shropshire, and occupy separate ridges on the south-eastern flanks of the Wrekin and Caer Caradoc.

In this paper Murchison remarks (p. 476) that towards the base of the Lower Ludlow Rock (3) a thin calcareous zone is observable in Shropshire, containing *Pentamerus lævis* and a new species of that bivalve differing from the species (*P. knightii*) noted in the overlying group (2).

In the second paper (1834) he gives the following classification, in which the local names of Horderley and May-Hill Rocks are given to the group of Shelly Sandstones (No. 4) and local names to each of the remaining groups :—

1. Ludlow Rocks.
2. Wenlock and Dudley Rocks.
3. Horderley and May-Hill Rocks.
4. Builth and Llandeilo Flags.
5. Longmynd and Gwastaden Rocks.

'The name of May Hill in Gloucestershire is added to that of Horderley, because in that well-known hill, several members of the formation (particularly the red and shelly sandstone) are well exhibited.'

On another page he remarks :—

'May Hill, in Gloucestershire, is cited as a good type of the formation, where it is also overlaid by superior deposits.'

He observes also (p. 15) that the impure limestone at the base of the Wenlock Shale, and constituting the top of the shelly sandstones, is strongly marked by its peculiar character and organic remains.

The views of Murchison received fuller exposition when his 'Silurian System' appeared in 1839, and a great many fossils from the various groups were figured and described by well-known palæontologists.

The Horderley and May-Hill Rocks there received the collective name of Caradoc Sandstone, which therefore comprised the rocks between the Llandeilo Flags beneath and the Wenlock Shale above.

The terms Upper and Lower Silurian were also introduced, the former to include the Wenlock and Ludlow formations and the latter the Caradoc Sandstone and Llandeilo Flags.

The organic remains of the Caradoc Sandstone were copiously illustrated and described; but the peculiar calcareous band mentioned in his earlier papers as occurring at the base of the Wenlock, characterized by *Pentamerus lævis*, etc., was now united with the Caradoc Sandstone, and its fossils were described along with those from that formation. This was an unfortunate step, as it obscured the relation of the fauna to that of the Wenlock Series, and gave a false impression of a close affinity between the Lower and the Upper Silurian faunas.

The range of these rocks along the Welsh borders and into

South Wales is described in some detail. Special reference is made to their development in the neighbourhood of Llandovery, as it was supposed that in that district there was exhibited

'a passage on the one side into the Upper Silurian rocks, and on the other into the Upper Cambrian' (p. 352).

The fossils in the sandstones in the hilly tract of Noeth Grug and Cefn-y-garreg were believed to be

'specifically identical with well-known shells of the Lower Silurian rocks; while the beds in which they occur graduate on one side into the Cambrian rocks, and on the other into Lower Silurian rocks. Occupying, therefore, the base of the latter system, these beds must underlie the Llandeilo flags, which are here represented by a thick zone of black flag-like beds, though I could find no traces of the characteristic trilobites.'

These 'Llandeilo Flags' are represented near Cerig Gwynion on the section accompanying the 'Silurian System' (pl. xxxiv, fig. 3).

Murchison remarks that, in the environs of Llandovery, the Lower Silurian rocks are in some places not easily separable from the Upper by mineral characters.

While Murchison was attempting to work out the relations of the rocks below the base of the Old Red Sandstone along the Welsh Borderland and in South Wales, Sedgwick was attacking the far more difficult problem presented by the great series of rocks in North Wales; he began with the oldest rocks, and worked upwards. In view of the complicated structure of Wales, we can now see how inevitable it was that these two investigators would meet with rocks of the same age, but of different appearance, in the respective districts with which they dealt. Thus arose the controversy on matters of classification and nomenclature which, however unfortunate it was, nevertheless called special attention to the Welsh rocks, and led to the examination of the problems that they presented by a host of researchers.

Much of the misunderstanding had its origin in the usage of the terms Llandeilo and Caradoc, and in the misinterpretation by Murchison of the structure of that part of South Wales which lies immediately west of the tract called Siluria. He had formed the opinion, without having examined them in detail, that the slaty rocks north-west of Llandeilo, for instance, were, by reason of their more crystalline character, a group older than the shales and mudstones of the Llandeilo and Caradoc, and must, therefore, belong to Sedgwick's Cambrian. Sedgwick, on the other hand, having cursorily examined their relations to the rocks of North Wales, regarded them as a development of his Upper Cambrian or Bala Group. As this group was later admitted to be in North Wales indistinguishable by its fossil contents from the Caradoc rocks of Murchison, the slaty rocks near Llandeilo should, therefore, be younger than the Llandeilo Series. It is interesting to note that the region which brought the controversy to a head was one which neither of the protagonists had

examined in detail. It was Sedgwick's contention that Murchison had misinterpreted the position of the Llandeilo rocks, while Murchison claimed that the Upper Cambrian of Sedgwick could be proved by its fossils to be equivalent to the Caradoc and Llandeilo Groups.

It is now known that in this, as in other cases, Sedgwick's stratigraphical work was wonderfully good, and there is no doubt that, as a group, the Bala was more homogeneous, and rested on a firmer stratigraphical basis than the Llandeilo and Caradoc of Murchison.

The inferior limit of the Bala was finally taken at the base of the black shales overlying the highest porphyries of Arenig and Cader Idris, while the superior limit was defined by the base of the Wenlock, the lowest of Murchison's groups, the relation of which to the adjacent formations could not be called in question.

A difficulty arose in parts of North Wales, inasmuch as a group of sandstones there underlay shale of Wenlock type. These the officers of the Geological Survey and Murchison for many years regarded as Caradoc ('Welsh Caradocs'),[1] because, like those rocks in Shropshire, they formed a sandstone group underneath the Wenlock. Sedgwick proved, by an examination of their fossils, that they were indistinguishable from the Wenlock Shale above them, and he definitely grouped them with that formation under the name of Denbighshire Sandstones, the upper part of the Bala being then formed by pale, earthy, slaty rocks upon which those sandstones rested.

A few years afterwards Sedgwick, with the assistance of McCoy and Salter as palæontologists, devoted special attention to the fossil contents of the Caradoc of Murchison and the Geological Survey.[2] He was able to show that the rocks of the May-Hill district which had been called 'Caradoc Sandstone' were intimately allied to the overlying Wenlock rocks, and should in reality be regarded as a basal type of Wenlock. He, therefore, proposed[3] for them the name of 'May Hill Sandstones,' which had, in fact, been applied to them by Murchison in one of his early papers. He proved, also, that they were totally distinct from the main mass called 'Caradoc' in Shropshire; but he failed in the time at his disposal to recognize these May Hill Sandstones between the typical Caradoc and the Wenlock Shale of Shropshire.

After the reading of Sedgwick's paper to the Geological Society in November 1852, the Geological Survey dispatched Aveline

'to re-examine the boundary-line between the Caradoc Sandstone and the Wenlock shale along the base of the Wenlock Edge, where the "*Pentamerus* Beds" had been described ("Silurian System") as forming an intermediate or passage group from the Lower to the Upper Silurian, and to draw the line at the base of those beds, if they should prove distinct from the lower and more typical portion of the "Caradoc." It was, also, necessary to ascertain whether these

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[1] R. I. Murchison, 'Siluria' 5th ed. (1872) p. 103.
[2] Q. J. G. S. vol. viii (1852) p. 136.
[3] *Ibid.* vol. ix (1853) p. 215.

"*Pentamerus* Beds" could be identified with the "upper portion" of the Caradoc developed at May Hill and the Malverns, and which has lately been described by Professors Sedgwick and McCoy . . . .'[1]

It had been noted by A. C. Ramsay & W. T. Aveline in 1848[2] that a part of the Caradoc in Shropshire behaved in a different manner from the rest of it, and persistently followed the base of the Wenlock. Its fossils were enumerated by Forbes.

Also J. A. Phillips[3] had shown that in the Malvern and Abberley districts the so-called 'Caradoc' was intimately connected with the Woolhope Limestone, and no definite line of separation could be drawn between them. The fossil lists from the 'Caradoc' and the Woolhope are closely alike, yet the remarkable statement is made that

'it is unquestionable that the former belongs, by its organic contents, to the Lower Silurian group, and the other, by the same characters, is inseparately linked with the Wenlock rocks' (p. 74).

Sedgwick's work furnished a ready explanation of these anomalies, and marked a most important step in advance. They were further elaborated in a paper read to the Geological Society on May 3rd, 1854, of which, however, only a short abstract was published by the Society. The paper appeared subsequently in the 'Philosophical Magazine' for 1854 (ser. 4, vol. viii, pp. 301, 359).

The re-examination of the Shropshire area by Aveline & Salter led to most important results, not only in regard to the relations of the rocks in that area, but also along the Welsh Borders. These authors confirmed Sedgwick's views as to the distinctness of the upper and lower portions of the Caradoc, and were able, also, to establish the fact of a great unconformity between them.

They concluded from the fossil evidence that the typical Caradoc was equivalent to the Bala, and the overlying rocks to the May-Hill Sandstone. Further, a band of purple and greenish shales was observed everywhere between the Upper Caradoc sandstones and the base of the Wenlock. It was this peculiar band which in the succeeding two or three years furnished the clue that brought the Welsh rocks into relation with those of Shropshire.

During a great part of the year following the publication of the above-mentioned paper, Aveline was engaged in examining the rocks lying west of the base of the Wenlock in the neighbourhood of Llandovery and Builth, and in the district on the north. During this survey pale slates of the Shropshire type were observed between the '*Pentamerus* Sandstones' of Castell Craig Gwyddon, north-east of Llandovery, and the base of the Wenlock. As the pale slates appeared from their geological characters and position to be equivalent to those of Shropshire, it followed that the underlying sandstones were the representatives of the Shropshire *Pentamerus* Beds. This view was confirmed by Salter from

[1] W. T. Aveline & J. W. Salter, 'On the "Caradoc Sandstone" of Shropshire' Q. J. G. S. vol. x (1854) pp. 62–63.

[2] *Ibid.* vol. iv (1848) p. 294.

[3] Mem. Geol. Surv. vol. ii (1848) pt. 1.

examination of the fossils. Aveline further observed that similar pale slates adjoined the Wenlock in many parts of North Wales, while north of Builth they were proved to underlie the sandstones which the surveyors had been in the habit of calling the 'Welsh Caradocs.' The fossils of those sandstones were, therefore, carefully re-examined, and it was shown that they should be assigned to the Wenlock, as had been demonstrated nearly ten years previously by Sedgwick in North Wales.

Towards the end of the same year Aveline discovered that 'the *Pentamerus* Sandstones' of Castell Craig Gwyddon, which had been identified with the Shropshire *Pentamerus* Beds, were underlain by another great series of sandstones also containing *Pentamerus,* the species of which were, however, shown by Salter to be different from those of the upper sandstones. The terms 'Upper' and 'Lower *Pentamerus* Sandstones' then became current for a short period, until it was decided to give them a more suitable name. Hitherto the upper sandstones had been called by the Geological Survey, Upper Caradoc, although Sedgwick had previously shown that they were equivalent to the May-Hill Sandstones; while the lower sandstones had received no local name. When the term Upper Caradoc had been shown to be unsuitable, Murchison proposed the name of Llandovery Sandstones to include the lower and upper series (see below).

Aveline believed at one time that he could separate the Lower *Pentamerus* Sandstones from the underlying contorted slaty rocks, and attempted to map a line at their base. He was forced to abandon this attempt; but he was able to show that the upper sandstones were distinguished from the lower, and completely overlapped them in the course of a few miles. The relations of the two groups were, in fact, suggestive of an unconformity between them; and on this ground it was decided to extend the Upper Silurian down so as to include the Upper *Pentamerus* Sandstones, and to relegate the Lower *Pentamerus* Sandstones to the Lower Silurian. This course had previously been proposed by Sedgwick after an examination of the May-Hill district, where, however, the lower group is not represented. In the 4th edition of 'Siluria,' published in 1867, the name 'Llandovery rocks' was introduced by Murchison, and the two groups of sandstones were styled Lower and Upper Llandovery (p. 85). There still remained as a nameless group the pale shales which intervene between the Upper Llandovery and the base of the Wenlock. Aveline, having traced, in 1855 and 1856, shales of this character from Llandovery into North Wales, proposed for them the name of Tarannon Shales, by reason of their great development in that locality. Since that time (1857) until recent years the classification adopted on the maps and in the Memoirs of the Geological Survey was (*a*) Lower Llandovery, forming the upper part of the Lower Silurian; (*b*) Upper Llandovery; and (*c*) Tarannon, forming the lower members of the Upper Silurian. The affinities of the Tarannon Shales have given rise to differences of opinion. Ramsay and Aveline were

inclined, on the ground of their physical relations, to class them with the Wenlock; while Salter maintained that their palæontological affinities were with the Upper Llandovery.

Murchison[1] regarded them as occupying an intermediate position connecting the Lower with the Upper Silurian rocks. On account of the unsettled status of this group, it became customary to use the term Llandovery-Tarannon in referring to the rocks between the Bala or Caradoc and the Wenlock.

In 1875 T. McKenny Hughes[2] suggested that the base of the Silurian of Sedgwick (Upper Silurian of Murchison) should be drawn, not between the Upper and Lower Llandovery, but at the base of the latter, and he proposed the name May-Hill Series to include the Upper and Lower Llandovery and the Tarannon. This was adopted by H. B. Woodward in his 'Geology of England & Wales,' where these rocks are arranged as follows:—

May-Hill Series	Tarannon Shales. Upper Llandovery. Lower Llandovery.

It is doubtful whether the extension of the name May Hill to include the Lower Llandovery rocks is justifiable, since there is no evidence of this group in the type-district of May Hill.

The proposal to include the Lower Llandovery in the Upper Silurian which had been urged, also, by Lyell, Hicks, and others, was destined to receive support about two years later from an unexpected quarter. In 1878 was published Charles Lapworth's remarkable paper on 'The Moffat Series,'[3] wherein he compares the three divisions (Glenkiln, Hartfell, and Birkhill) there established with the three successive formations Llandeilo, Bala, or Caradoc, and Llandovery of Siluria. The correlation of the two lowermost divisions was based on a comparison of the graptolite species which were known to be common to the Scottish and the Welsh deposits, or their undoubted foreign equivalents; but, as not 'a single species of the Birkhill fauna' had at that time been 'recorded from any of the Silurians of the Principality,' he was unable to make a direct correlation based on community of species.

The Coniston mudstones were, however, known to occupy a position above the equivalents of the Bala Limestone, and were crowded with typical Birkhill forms. Also, identical species had been recorded from the Kieselschiefer of Thuringia, which were placed by Murchison and others at the junction of the Lower and the Upper Silurian, while they were known to occur in the Upper Graptolite Shales of Sweden, which overlie everything to which the name Bala could be applied. From these considerations Lapworth was able to affirm that the Birkhill shales were of Lower Llandovery age. Two years later he followed up this paper by a remarkable series of papers on 'The Geological Distribution of the Rhabdophora'[4] in which he brings together all the information

[1] 'Siluria' 5th ed. (1872) p. 103.
[2] Rep. Brit. Assoc. (Bristol) 1875, Trans. p. 70.
[3] Q. J. G. S. vol. xxxiv (1878) p. 240.
[4] Ann. Mag. Nat. Hist. ser. 5, vol iii (1879) p. 455 & vol. v (1880) p. 45.

then available for the correlation of the graptolitic facies of Birkhill and Gala with the divisions of the older classification. After summarizing the evidence, he remarks (*op. cit.* vol. v, p. 47) that three distinct groups of strata separated by fairly marked unconformities are found in many parts of Wales between the summit of the Bala and the base of the Wenlock Shale :—

'It has generally been the habit to call the first of these subformations by the title of the Lower Llandovery, the second May Hill or Upper Llandovery, and the third the Tarannon shale. The first is usually believed to be most intimately allied in its palæontological characters to the Bala formation, and the last to be hardly separable from the Wenlock shale. My own researches impel me to the conclusion that these three subformations are far more closely allied to each other than they are to the beds above or below, and that they should be considered as the three consecutive members of a single formation. In the South of Scotland (Valentia) these three subformations are recognizable, superposed in conformable sequence with clear relations to the Bala below and to the Wenlock above, and unitedly covering an area of several thousands of square miles. Until geologists are willing to include the Tarannon in the Llandovery, it will therefore be best to speak of this great Scottish formation and its equivalents as the Valentian formation, its three divisions (Lower, Middle, and Upper) representing respectively the Lower Llandovery, Upper Llandovery, and Tarannon of Wales and Siluria.'

It will be observed that Lapworth apparently implies the correlation of the Lower Birkhill, Upper Birkhill, and Gala (including Hawick) subdivisions which he had previously established in the South of Scotland with Lower Llandovery, Upper Llandovery, and Tarannon respectively. If this suggestion is examined it will be found, however, that the meaning of both Upper Llandovery and Tarannon varies according to the facies of the rocks which is in question. It is doubtful, moreover, whether such a correlation was intended by Lapworth, for, on another page (*op. cit.* vol. v, p. 364), he writes :

'In the entire series we seem at present to recognize five subgroups of tolerably equal systematic importance—the (1) Lower, (2) Middle, and (3) Upper Birkhill Shales, and (4), (5) the Gala and Grieston groups. Of these, Nos. 1, 2, and 3 are possibly included in the so-called Lower Llandovery of South Wales, while the fourth and fifth correspond to the Upper Llandovery and Tarannon' ;

and on p. 365 he uses Gala and Tarannon as if they were synonymous terms. The correlation of the Birkhill with the Lower Llandovery is in accordance with his conclusions in the paper on the Moffat Series (see above); while he had previously demonstrated [1] that the Gala rocks pass up conformably into the Riccarton Beds—the representatives of the Wenlock in the South of Scotland.

Most of the confusion which attaches to the classification of the Valentian rocks of different areas is due to the ambiguous relation one to the other of the Tarannon and Upper Llandovery groups. From their lithological characters and their position immediately underneath the Wenlock Shale, the pale shales of the neighbourhood of Llandovery and of Shropshire were believed by Aveline to be the same rocks as those at Tarannon. Aveline traced these

[1] Geol. Mag. 1876, p. 550.

peculiar rocks continuously from Tarannon to Conway in North Wales, where again they underlie the Wenlock, and naturally concluded that they were of the same age in these two localities. On Tarannon the shales are underlain by a great grit group; but, as these beds disappear before reaching Conway, Aveline concluded that they had been overstepped by the Tarannon, and that in consequence the two groups were not conformable one to the other. He had previously found that the pale shales behaved in a similar way towards the Lower Llandovery rocks of the Llandovery district; and as the grits of Tarannon showed some similarity of lithological characters to supposed Lower Llandovery grits of various parts of Wales, they were assigned on these grounds to that formation.

When, in 1870, Lapworth discovered in the Tarannon Shales of Conway many of the same species of graptolites as those that he had found in the lower part of the Gala Group, he concluded that the Tarannon Shale occupied the systematic position of that group. This correlation of the Tarannon with the Gala, and the Birkhill with the Lower Llandovery, left no room for the Upper Llandovery; whereas, in the Llandovery district that formation lies between the Tarannon and the Lower Llandovery. This conflicting evidence in regard to the relations of these formations received no explanation until the Tarannon area was carefully revised by Dame Ethel Shakespear (Wood).[1] The peculiar purple and green shales (renamed the Dolgau Beds) to which the name Tarannon Shales was given by Aveline are underlain conformably by a great series of rocks which contain many species of graptolites. Those of the shales and of the Talerddig Grits, on which they rest, are closely allied. Below the grits are the Gelli and Brynmair Groups, and below the latter, representatives of the Upper Birkhill and of the Lower Birkhill faunas were proved. The Dolgau Beds cannot be dissociated from the underlying strata, and on faunal grounds all four groups make up one homogeneous formation.

Dame Ethel Shakespear considered that the Tarannon Shales of Conway are equivalent to the two lower groups only of the Tarannon sequence, and the two upper groups are not represented; but, in a later account of the district, Miss G. L. Elles[2] records the highest zone (*Monograptus crenulatus*) in beds which pass up conformably into the Wenlock. The underlying zone of *M. griestonensis* is believed to be represented by unfossiliferous shales. Detailed comparison of the faunas proved the exact parallelism of the Tarannon Series with the Gala Beds of the South of Scotland: the true Tarannon Shales being represented in all probability by the Hawick rocks, which occupy a position immediately below the Riccarton rocks or the equivalents of the Wenlock Shale.

The investigation of the Tarannon and Conway areas thus proved that the 'Pale Slates' mapped by Aveline are not a homogeneous formation, but a group in which, while certain lithological characters are retained, the lower limit varies from point to point of the outcrop.

[1] Q. J. G. S. vol. lxii (1906) p. 644. [2] *Ibid.* vol. lxv (1909) pp. 186 & 189.

II. Classification of the Graptolitic Facies of the Valentian.

The relation of the Tarannon rocks to the Birkhill and Gala having thus been established, it remains to consider the systematic position of the Llandovery rocks. On account of the striking difference between the almost exclusively shelly fauna of the Llandovery and the almost exclusively graptolitic fauna of the Birkhill and Gala, a comparison between them is exceedingly difficult. It is only rendered possible, in fact, by the existence of certain developments or facies which are partly shelly and partly graptolitic, and by the rare occurrence of graptolites in the shelly facies of some districts, or of shelly fossils in the graptolitic facies.

A standard for comparison is afforded by the succession of the various forms of graptolites, which has been worked out in great detail in many areas, notably in the Moffat district (C. Lapworth),[1] Lake District (J. E. Marr & H. A. Nicholson),[2] Conway (G. L. Elles & E. M. R. Wood),[3] Rhayader (H. Lapworth),[4] Plynlimon and Machynlleth (O. T. Jones & W. J. Pugh).[5] There is no reason to believe that the subdivision of these rocks has been pushed too far, and when detailed comparisons are made between the graptolitic developments in different areas, it is possible to identify even smaller subdivisions in districts as wide apart as Scotland or the Lake District and Central Wales.

A general classification of the graptolitic facies of the Valentian Series may, therefore, be drawn up as follows (the subdivisions of the older-established main groups being slightly rearranged in accordance with the results of more recent investigations):—

Valentian Series.	Gala Stage or Upper Valentian.	Upper Gala sub-stage, comprising the zones of *Monograptus crenulatus* and *M. griestonensis*.
		Lower Gala sub-stage, including the zones of *Monograptus crispus*, *M. turriculatus*, and *Rastrites maximus*.
	Birkhill Stage or Lower Valentian.	Upper Birkhill sub-stage, formed by the zones of *Monograptus halli* and *M. sedgwicki* (=*spinigerus*).
		Middle Birkhill sub-stage, with the zones of *Monograptus convolutus* (including *Cephalograptus-cometa* sub-zone), *M. leptotheca*, *Mesograptus magnus*, and *Monograptus triangulatus*.
		Lower Birkhill sub-stage, including the zones of *Monograptus cyphus*, *M. acinaces* (=' *rheidolensis* '), *M. atavus* (=' *tenuis* '), *Mesograptus modestus*, *Cephalograptus ? acuminatus*, and *Glyptograptus persculptus*.

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[1] Q. J. G. S. vol. xxxiv (1878) p. 240.
[2] *Ibid.* vol. xliv (1888) p. 654.
[3] *Ibid.* vol. lii (1896) p. 273 (G. L. Elles & E. M. R. Wood); & vol. lxv (1909) p. 169 (G. L. Elles).
[4] *Ibid.* vol. lvi (1900) p. 67.
[5] *Ibid.* vol. lxv (1909) p. 463 (O. T. Jones); & vol. lxxi (1915–16) p. 343 (O. T. Jones & W. J. Pugh).

There is some difference of opinion as to the position to be assigned to the *Rastrites-maximus* Zone. Charles Lapworth, Miss Elles, and Dame Ethel Shakespear advocate its inclusion with the overlying group, and their opinion is adopted in the foregoing scheme. In the Lake District its affinities seem to be closer with the underlying than with the overlying group. There is reason to believe that *Rastrites linnæi*, which occurs frequently in the upper part of the Birkhill Stage, has sometimes been mistaken for *R. maximus*, and this may account for some of the differences of opinion noted above. The only district in Central Wales where *R. maximus* has been identified with certainty is in the Twymyn Valley (Tarannon), where its affinities are clearly with the overlying beds. There is some doubt also about the position of the zone of *Mesograptus modestus*, as this form has been quoted from most horizons, from the zone of *Glyptograptus persculptus* to that of *Monograptus triangulatus*.

III. The Girvan Mixed Facies.

A direct comparison of the shelly facies with the graptolite scale can be made by reason of the magnificent development in the Girvan district, where shelly sandstones and mudstones alternate with grey and black graptolitic shales, especially in the Lower Valentian. The classification given by Charles Lapworth[1] may be slightly rearranged, in order to bring it into accordance with the graptolitic scheme, as follows:—

Valentian Series.	Upper Valentian or Dailly Stage.	Drumyork Group. Bargany Group. Penkill Group. Camregan Group.
	Lower Valentian or Newlands Stage.	Saugh-Hill Group, including the following subdivisions:— (*a*) Zone of *Monograptus sedgwicki* (=*spinigerus*). (*b*) Saugh-Hill Sandstones (unfossiliferous). (*c*) Zone of *Diplograptus modestus*. (*d*) Woodland Conglomerate, Limestone, and Mudstone.
		Mulloch-Hill Group, divided into: (*a*) Zone of *Diplograptus acuminatus*. (*b*) Mulloch-Hill Sandstones and Conglomerates.

The Camregan Group, which was originally included in the Newlands stage, consists of yellow blue-hearted grits, with rare *Rhynchonella*, etc., which pass up into fossiliferous calcareous flagstones and limestones. The latter pass gradually upwards

[1] Q. J. G. S. vol. xxxviii (1882) p. 537.

into blue shales, and these in turn into green and purple mudstones which contain near their centre the *Rastrites-maximus* shale-band.

'These *Rastrites-maximus* mudstones pass upwards into a group of massive yellow gritstones very similar in their petrological characters to those which succeed to the *M.-sedgwickii* zone. . . . . About 60 feet of these pale-yellow gritstones are here exposed, and form the final member of this . . . Camregan group' (*op. cit.* p. 647).

If the *Rastrites-maximus* Zone is united with the Upper Valentian, it is impossible not to include with it the rest of the Camregan Group, and accordingly it is here included with the overlying Dailly Stage. There is, moreover, no clear evidence of a close relationship between the lower sandstones of the group and the *Monograptus-sedgwicki* Shales which adjoin them, as the junction is a fault. On all grounds, however, it is certain that the Camregan Group occupies a higher stratigraphical position than the shales. Further, it will be shown in the sequel that the shelly fauna of that group in the Girvan district (and its representatives elsewhere) has many features which unite it with the Upper Valentian and late Silurian rocks rather than with the Lower Valentian.

It is preferable to modify the existing classification in accordance with recent discoveries rather than abolish it in favour of a new scheme.

IV. Comparison of the Shelly Horizons of the Girvan Succession with the Graptolitic Scale.

Newlands Stage.—The Mulloch-Hill Beds occupy the time-interval between the base of the Valentian Series and the horizon of the Glenwells Shales. These shales are comparatively barren; but Charles Lapworth records *Climacograptus scalaris* (var. *normalis ?*), *Dimorphograptus (Diplograptus) acuminatus*, and *(?) Monograptus tenuis*.

No species of *Monograptus* has been recorded in any other area from the same horizon as *Diplograptus acuminatus*. If the specimen doubtfully recorded above was a *Monograptus*, it may have been obtained on a higher level than *D. acuminatus*; but, as the total thickness of shales exposed in Glenwells Burn is comparatively small, the occurrence of both species in the same section would indicate that the Glenwells Shales represent a horizon at the junction of the two zones, which would enable their position to be fixed very accurately on the graptolitic scale. If this record of *Monograptus* is erroneous, all that can be stated is that the Glenwells Shales form some part of the *D.-acuminatus* Zone. That zone appears to extend in the South of Scotland almost, if not quite, to the base of the Valentian, and the great mass of the Mulloch-Hill Sandstone and Conglomerate must represent the lower part of the zone, thus corresponding in point of time to a very small thickness of graptolitic shales.

The Newlands *Pentamerus* Beds.—These are included between the graptolitic shales of Glenwells Burn and those of

Glenshalloch Burn, and it is of importance to fix as precisely as possible the lowest horizon represented by the latter. The graptolites quoted by Charles Lapworth comprise a number of species which have been proved by subsequent work in other districts to be characteristic of different horizons. The section was, therefore, examined by me in 1909, in company with Mr. Macconochie, and four distinct horizons distinguished by the following forms were recognized (only the important forms being quoted):—

(*a*) The lowest horizon yielded *Monograptus sandersoni*, *M.* cf. *triangulatus*, *M. gregarius*, and *Climacograptus hughesi*. The association of the two first-named fixes the horizon accurately as the lowest part of the *M.-triangulatus* Zone.

(*b*) The next horizon in ascending order yielded *Monograptus communis* c., *M. gregarius* v. c., *Rastrites longispinus* v. c., *Glyptograptus tamariscus*, *Climacograptus tœrnquisti*, *Cl. hughesi*, and *Retiolites perlatus*. An identical *Rastrites* has been found to characterize a horizon in the *M.-triangulatus* Zone in Central Wales, where *Monograptus communis* and *M. gregarius* also occur abundantly.

(*c*) A third horizon yielded *M. gregarius*, *M. argutus*, *M.* cf. *communis* c., and *M.* cf. *fimbriatus* c. The *communis* and *fimbriatus* forms are characteristic of the zones of *Mesograptus magnus* and *Monograptus leptotheca* in Central Wales, where *M. argutus* also makes its first appearance in the ascending succession.

(*d*) The highest horizon from which graptolites were obtained furnished the following species:—*M.* cf. *communis* in swarms, identical with the form found in Wales; *M. triangulatus*, var. *major*, *M.* cf. *difformis* or cf. *argenteus* v. c. (very like an abundant form in the Welsh *M.-leptotheca* Zone), *M.* cf. *mirus*, *M. leptotheca*, etc.

The identity of this horizon with the *M.-leptotheca* Band as developed in Wales can hardly be doubted; almost every form peculiar to that band is represented. Also, the few feet which are exposed of the succeeding strata, though yielding no fossils, bear a strong lithological resemblance to the mudstones which follow those shales in Wales.

The Glenshalloch Shales coincide precisely, therefore, with the zones of *Monograptus triangulatus*, *Mesograptus magnus*, and *Monograptus leptotheca*, and it is noteworthy that at Girvan, as in Central Wales, four distinct horizons can be recognized. The Newlands *Pentamerus* Beds must, therefore, occupy at most the time-interval between the zones of *Diplograptus acuminatus* and *Monograptus triangulatus*. A small thickness of greenish shales in which no fossils were found intervenes between the shelly beds and the graptolitiferous shales, so that the time-interval is probably somewhat less than is inferred above.

The Woodland Limestone and fossiliferous Shales.—According to Lapworth's interpretation of the structure of this area, the superior limit of this group is marked by the horizon of the graptolitic shales which occur in association with it. From the list given by that author this level cannot be accurately determined, since *Diplograptus modestus* and *Monograptus leptotheca* are recorded from the same locality, though only a few feet of strata are exposed. It may be suggested that the latter form was one of the *Monograptus-cyphus* or *M.-revolutus* group, the distal portions of which resemble fragments of *M. leptotheca*.

From the Shalloch Forge locality, where the same shales are exposed, *Diplograptus modestus* was also obtained, but in association, among others, with *Monograptus cyphus*. Most of the forms which have been referred to *M. cyphus* indicate a horizon not higher than the lower part of the *M.-triangulatus* Zone. A search made by me at this locality yielded the following forms:—*Monograptus revolutus* c. and var. *austerus*, *M. sandersoni*, *M.* sp. (which is almost certainly *M. atavus*), *Mesograptus modestus* var. *diminutus*, and an extraordinary abundance of *Glyptograptus tamariscus*. The general association of these graptolites, especially the occurrence of *M. sandersoni* and the absence of *Monograpti* of the *triangulatus* or *communis* types, probably indicates the *M.-cyphus* Zone in its restricted sense. The horizon is, therefore, fixed within narrow limits, since that zone is in most areas of small thickness.

According to Lapworth, the highly-fossiliferous Woodland Limestone and Shale occur not far beneath the graptolitic shales. As noted above, the lowest graptolitic horizon exposed in the Newlands region is the lowest part of the *M.-triangulatus* Zone, and therefore only just above the Shalloch Forge horizon; even in districts where the Birkhill sequence is of considerable thickness, the difference in stratigraphical level between these horizons does not amount to more than a few feet. It is probable that, as Lapworth suggested, the Woodland Beds do not immediately underlie the graptolitic shales, but are equivalent to a thin calcareous seam in Penwhapple Glen, which is also associated with graptolitic shales. An examination of numerous specimens from this locality, preserved in the collection of the Geological Survey of Scotland, allows the horizon of these shales to be fixed with considerable precision. The most important forms identified were:—*Monograptus atavus* v.c., *M.* sp. different from *atavus*, but recalling *M. acinaces*, *Dimorphograptus confertus* c., *D.* cf. *longissimus* v.c., *D.* cf. *erectus*, *Climacograptus tœrnquisti*, and some others. *Monograptus revolutus* and *Mesograptus modestus* var. *diminutus* were collected by Mr. Macconochie and myself during our visit. The association of abundance of *Monograptus atavus* with various Dimorphograptidæ and *Climacograptus tœrnquisti* indicates a horizon near the top of the *M.-atavus* Zone of Central Wales; but the presence of a second species of *Monograptus* points to a slightly higher level, the difference being, however, only a few feet.

The Woodland Beds apparently occupy a position immediately below this horizon, and they correspond, therefore, to the interval represented by the *Monograptus-atavus* Zone, and possibly a part of the succeeding *M.-acinaces* Zone.

The Dailly Stage: the Camregan Limestone Group.—The reasons for including this group with the Upper Valentian have already been stated; the position of the group on the graptolitic scale is clearly defined by the zone of *Rastrites maximus* within it. An approximate lower limit is indicated by the fact that

the underlying shales contain the characteristic fauna of the *M.-sedgwicki* Zone, although the stratigraphical relations are disturbed by a fault. The time-interval between the *M.-sedgwicki* and *Rastrites-maximus* Zones is nowhere very great, if one may judge by the thickness of sediment, and it is probable that the disturbance produced by the intervening fault is comparatively small.

The shelly horizons of Girvan can thus be fixed within narrow limits on the graptolitic scale, and by comparison of the shelly facies of other areas with that of Girvan they can be brought into relation with the same scale. Some assistance in this comparison is afforded by the Valentian rocks of the Lake District, in which J. E. Marr & H. A. Nicholson [1] have recorded various species of trilobites from the mudstones which divide the graptolitiferous shales.

V. Comparison of the Haverfordwest Succession with that of Girvan.

The Haverfordwest district, where the shelly facies is more completely represented than anywhere else in Britain, affords the most satisfactory comparison with Girvan. During the recent re-survey of that district the following classification of the Valentian Series was adopted :—

Valentian Series.	Millin Stage.	Canaston Beds.
		Uzmaston Beds.
	Haverford Stage.	Gasworks Sandstone.
		Gasworks Mudstone.
		Cartlett Beds.
		Basement Beds.

A few miles south of Haverfordwest the Valentian is represented by the Rosemarket Stage, which rests unconformably on the Pre-Cambrian. The facies is totally distinct from that of Haverfordwest, and resembles more nearly that of Wooltack and Marloes, or of the May Hill and other districts in the South-West of England. Its relation to the Millin Stage is discussed below.

A few graptolites have been collected near Haverfordwest, and they enable certain horizons to be determined approximately by direct reference to the graptolitic scale. A form of *Mesograptus modestus* which was obtained near the base of the Cartlett Mudstones seems to be allied to the variety *parvulus* H. Lapworth, which is characteristic of the *Glyptograptus-persculptus* Zone in Central Wales. The local base of the Valentian in this district may, therefore, be assumed to represent approximately the same horizon as the base of the Birkhill in those areas where the graptolitic sequence is complete.

[1] Q. J. G. S. vol. xliv (1888) p. 654.

A few specimens of *Climacograptus scalaris* var. *normalis* have been obtained from the Gasworks Beds. This variety is stated in the Palæontographical Society's 'Monograph of British Graptolites' to survive into the zone of *Monograptus gregarius* (of Lapworth), but never into the Upper Birkhill. The Gasworks Beds accordingly occupy a horizon not higher than the zone of *Monograptus convolutus* (of Marr & Nicholson, etc.).

A single specimen of *Climacograptus* was obtained in the strata which are considerably above the base of the Rosemarket Stage. The generic identification is certain, but its state of preservation is too poor to allow of the species being determined. Despite this fact, the discovery of any species of *Climacograptus* is important. According to the 'Monograph of British Graptolites,' *Cl. scalaris* occurs rarely, associated with *Rastrites maximus* and *Monograptus turriculatus*, in the Lower Gala Beds, and the genus is not known to occur anywhere above that horizon. It may be inferred that the local base of the Rosemarket Stage descends to a horizon near the base of the Gala or Upper Valentian Stage.

Shelly fauna.—It has been customary to regard the well-known fossiliferous mudstones of the Gasworks as the equivalents of the Mulloch-Hill Sandstones, largely on account of the abundance of the problematical *Nidulites favus* in both localities; but there are serious difficulties in accepting this correlation, and all the evidence indicates that their faunal affinities are rather with the Woodland Beds and the Newlands *Pentamerus* Group.

This conclusion is based mainly on a comparison which I have made between the brachiopod genera, *Pentamerus*, *Stricklandinia*, *Strophomena* (sensu lato), and *Plectambonites*, of the two districts and the trilobite genus *Phacops* (sensu stricto). These are represented by numerous forms, and a detailed study of the fossils of the Haverfordwest district has shown that many of them undergo progressive modifications in ascending order. They thus acquire a greater value for the purposes of correlation than forms for which no evolutionary history has been traced, however well marked they may be. A brief summary of these comparisons is all that can be attempted here.

The Pentamerids are represented in both districts by *Barrandella*, *Stricklandinia*, and possibly *Pentamerus*. A variety of *Barrandella undata* which is found in the Mulloch-Hill and Newlands Beds is characteristic of a horizon in the Cartlett Beds of Haverfordwest. The form which is so abundant in the Woodland Beds is different, and is not represented in the southern region (see, however, Llandovery district, p. 163). *Pentamerus oblongus* is recorded from the Newlands Beds; but, as it does not appear in Mrs. Gray's extensive collection, the record is open to doubt. A single specimen of *Pentamerus* sp. was found in the lower part of the Gasworks Mudstones.

Smooth forms of *Stricklandinia* which have commonly been attributed to *S. lens* occur in the Mulloch-Hill Beds, and less commonly in the Woodland and Newlands Beds. Similar forms

appear in the Cartlett Beds, and are characteristic of the greater part of the Haverford Stage.

In Scotland there is also found in the Woodland Beds a faintly-ribbed form which Dr. F. R. C. Reed refers to a variety of *Stricklandinia lirata*, and is not unlike one that occurs near the top of the Millin Stage. Unfortunately, the nomenclature of the forms of this genus is very unsatisfactory and needs revision. Dr. Reed,[1] in following Davidson, has perpetuated the existing confusion.

The Strophomenidæ, represented by *Strophomena*, *Stropheodonta*, *Schuchertella*, and other subgenera, are especially characteristic of the Woodland Beds, and the forms are closely analogous to those of the Gasworks Beds, although some of the latter appear to occur also in the Mulloch-Hill Beds. The most distinctive feature of the Haverford Stage is the abundance of forms of *Plectambonites* which are allied to *P. duplicatus*. The typical species occurs in swarms at the top of the Gasworks Mudstones; but in the lower parts of the stage well-marked varieties can be distinguished. It is possible, in fact, to use these forms to some extent as zonal indices. The genus is also represented in the Woodland Beds by swarms of individuals which agree in their stage of development with those of the lower part of the Gasworks Mudstones; while the presence of a few specimens of the typical form indicate an approach to the horizon at the top of the mudstones. Dr. Reed has erroneously referred these to *Plectambanites transversalis*, which is readily distinguishable from all forms of *P. duplicatus*, and is distinctive of the Wenlock rocks.

It is impossible, when comparing the brachiopod fauna from these distant localities, not to be impressed by the great resemblance between the Woodland fauna and that of the Gasworks Mudstones. There are, however, undoubtedly some forms in common with the Mulloch-Hill fauna; while the species ascribed by Dr. Reed to *Stricklandinia lirata*, var. *scotica* would seem to indicate a more advanced development than is shown by any of those from the Haverford Stage.

The majority of the forms of *Phacops* in the Haverford Stage may be referred provisionally to *Ph. elegans* Sars & Bœck, while others are intermediate between that species and *Ph. stokesi* Milne Edwards. The specimens from the Woodland Beds are identical with those which occur commonly in the Gasworks Mudstones. The Mulloch-Hill species seem to be specifically distinct, and have not been observed in the Haverfordwest district.

Again, the forms of the latter district are closely matched in the Middle and Upper Skelgill Beds of the Lake District, corresponding to the *M.-leptotheca* and *M.-convolutus* Zones.

The distribution of the species of *Phacops* thus confirms the impression conveyed by the more abundant brachiopods, and the correlation of the Woodland Beds with the main part of the Gas-

[1] 'The Ordovician & Silurian Brachiopods of the Girvan District' Trans. Roy. Soc. Edin. vol. li (1917) p. 795.

works Mudstones may be regarded as substantially correct. It is probable, however, that the upper part of the Haverford Stage extends beyond the upper limit of the Woodland Beds, and may thus be equivalent to the Glen Shalloch graptolite-shales. The Mulloch-Hill Beds probably correspond to the lower part of the Haverford Stage, which is relatively barren of fossils.

The Millin Stage.—The base of the Millin Stage in the Haverfordwest district has been taken at the bottom of a group of greenish, occasionally purple, rubbly unfossiliferous mudstones, which pass down conformably into the Gasworks Sandstone. On physical grounds this choice has little to recommend it; but, the boundary between the sandstone and mudstones being easily traceable, it facilitated the mapping. The mudstones are succeeded by a group of sandy pebbly beds which contain the characteristic fossils of the Millin Stage, and probably represent the true basal beds of that stage. In view of the remarkable contrast between the Millin fauna and that of the Haverford Stage, it is not unlikely that the pebbly beds mark an important change of physical conditions during the deposition of the sediments, if not a stratigraphical break. A change of physical conditions is, in fact, foreshadowed by the greenish and purplish rubbly mudstones which succeed the Gasworks Sandstone, and were formed under conditions unfavourable to organic life.

At the base of the Millin Stage several species appear for the first time in the ascending sequence, which either range up into the Wenlock, or are represented in that formation by closely-allied forms. Many of these are spire-bearing brachiopods which are markedly characteristic of the higher Valentian and Wenlock rocks: thus *Spirifer radiatus* and *Cyrtia exporrecta* both range into the Wenlock; while the abundant *Catazyga haswelli* is closely allied to the Wenlock *C. pentlandica*.

Many of the Strophomenidæ of this stage, such as *Schuchertella applanata*, are common Wenlock forms; while even the stage of development indicated by the varieties of *Leptæna rhomboidalis* is more nearly like that of the Wenlock than of the Haverford types.

The group of globose Pentamerids represented by *Barrandella globosa* and its varieties is unknown below this horizon, but they range upwards through the Valentian, and even in some localities (Marloes and Wooltack) possibly into the base of the Wenlock Series. Again, *Atrypa reticularis* appears in abundance at this horizon, but in the Haverfordwest district, at any rate, has not been found below: it is, of course, a well-known Wenlock species. The facies of the fauna is indeed so thoroughly reminiscent of the Wenlock Shale that, if it were not for the presence of certain Pentamerids and of species of *Phacops* which are not known to occur in the Wenlock, the Millin rocks might easily have been referred to that formation.

The stage is characterized by abundant forms of *Plectambonites*, which are readily distinguishable by their size, shape, and internal

characters from those of the Haverford Stage, and towards the top early variants of *Plectambonites transversalis* make their appearance. That species itself has not, hitherto, been proved to occur in the Valentian.

The foregoing summary of the faunal characters of the Millin Stage might be applied almost word for word to the Camregan Group of Girvan. Among other forms which occur in the Camregan Beds are *Barrandella undata*, var. *penkillensis* Reed (which is identical with that of the basal beds of the Millin Stage), *Catazyga haswelli*, *Spirifer radiatus*, *Cyrtia exporrecta*, '*Strophomena arenacea*,' and the abundant species of *Plectambonites* which Dr. F. R. C. Reed has also erroneously referred to *P. transversalis*. Many of the forms of *Phacops* are identical with those of the Millin stage, while in both districts there are examples intermediate between them and *Ph. stokesi*.

There is a further remarkable similarity in the lithological characters of the beds; the mudstones in both districts are greenish, and the fossils, where weathered, are preserved as casts coated with a pale-yellow limonitic material. The sandy beds are greenish with a bluish interior, while the basal beds in both districts are pebbly. There is, however, one striking difference: in the Camregan Group *Pentamerus oblongus* is an abundant fossil; but it has not been found so far in any part of the Millin Group. The distribution of this species is peculiar, and appears to be related to the conditions of deposition: it is abundant, for example, in the Caradoc and Rosemarket areas; while it is generally rare, or even absent, in the South-West of England and in the Marloes-Wooltack area. It is interesting to note, however, that it occurs in the Llandovery district associated with the most characteristic elements of the Millin fauna.

In the higher or Canaston subdivision of the Millin Stage *Barrandella globosa* is an abundant species, and is a characteristic index of the group. It is accompanied in some localities by a large variety. In the highest beds exposed in Pembrokeshire *B. globosa* is associated with numerous examples of a species of *Palæocyclus*. It is doubtful whether the typical *B. globosa* occurs in the Girvan district; it might be expected to occur in the Penkill Group, which is, however, largely of graptolitic facies except at a few horizons. It is of considerable interest to find that a small *Palæocyclus* which is indistinguishable from the Pembrokeshire specimens occurs abundantly at Blackwood Head Burn in company with *Pentamerus oblongus*. This horizon is in the Blackwood subdivision of the Bargany Group, which lies a considerable distance above the zone of *Cyrtograptus grayæ*, or, in other words, near the junction of the Lower and Upper Gala. The *Palæocyclus* Beds probably fall, therefore, within the Upper Gala, when referred to the graptolitic scale.

The Haverford Stage as a whole may, therefore, be compared with the two main fossiliferous groups of the Newlands Stage of Girvan; while the two subdivisions of the Millin Stage

probably correspond in point of time to the greater part of the Dailly Stage. Moreover, the close similarity between the fauna of the basal members of the Uzmaston Group and the Camregan Beds of Girvan indicates that the Millin Stage descends to the base of the Upper Valentian.

The Rosemarket Stage.—The relations of the Rosemarket to the Millin Stage and to the Wenlock rocks is unknown. The rocks occur in different areas, and the lithological and faunal facies are entirely different. The stage is distinguished by the abundance of *Pentamerus oblongus*, which occurs in the Upper Valentian of Scotland in the Camregan, Penkill, and Bargany Groups. Moreover, the discovery of a *Climacograptus* in beds considerably above the base suggests that the stage may descend as low as the base of the Upper Valentian, and may, therefore, be actually contemporaneous with the totally different development of the Millin Stage near Haverfordwest. The Rosemarket Stage can be considered most naturally with the well-known littoral facies which is developed in the Caradoc and other districts.

VI. The Llandovery District.

In this district three divisions have long been known, as the result of Aveline's work between 1855 and 1857. The classification is as follows:—

'Tarannon Shales'; purple and green shales.
Upper Llandovery; sandstones with *Pentamerus oblongus*.
Lower Llandovery; sandstones and mudstones with various species of '*Pentamerus*.'

The re-examination of the area upon which I am engaged has not, so far, resulted in the solution of all its problems; but the general succession can be stated.

The Lower Llandovery consists of a lower division of relatively barren mudstones and shales, with a basal group of sandstones and conglomerates, and an upper division of fossiliferous sandy mudstones with thin sandstones. The only part of the formation that is represented in museums is this upper subdivision, and from it were obtained the type-specimens of some well-known Llandovery species such as '*Atrypa*' (*Stricklandinia*) *lens* and '*Atrypa*' (*Barrandella*) *undata*. The lithological succession is, up to a point, remarkably like that of the Haverford Stage of Haverfordwest.

The brachiopod fauna of the upper division is almost identical with that of the Gasworks Mudstones, and like it is characterized by abundance of *Plectambonites duplicatus*, the type-specimen of which was collected by Murchison from these beds. From them also is derived one of the figured specimens of *Barrandella undata*, with which the form that occurs so abundantly at Haverfordwest and at Girvan in the Mulloch-Hill and Saugh-Hill Groups may be compared. The other figured specimens were derived from a different locality, but apparently from the same

strata; and this form is represented in the Woodland Beds of Girvan, though not in the Haverfordwest district. I have found no specimen of *Phacops* in the Lower Llandovery of the type area.

There appears to be no representative of the Gasworks Sandstone in that district; but the highest beds of the Lower Llandovery that are exposed contain *Plectambonites duplicatus* in great profusion, and these recall a horizon in the Gasworks Mudstones just below the sandstones.

The Upper Llandovery consists of a lower group, mainly of mudstones, and an upper group of sandstones. The fauna of the mudstones is distinguished by abundance of *Barrandella globosa*, one of the type-specimens of which was derived from these beds, and a small species of *Plectambonites*; *Catazyga haswelli* and *Cyrtia exporrecta* are also not uncommon. These forms indicate the similarity of the fauna to the Canaston Group of Haverfordwest; but at Llandovery they are associated with *Pentamerus oblongus*. The lithology of the rocks is closely comparable.

In the upper or sandstone division that species occurs in abundance, and in this and some other respects the division is comparable with the Rosemarket Stage. The special fauna of the Uzmaston Group of Haverfordwest has not been found so far. Its absence and that of the uppermost beds of the Haverford Stage suggest a physical break between the Upper and the Lower Llandovery of the type area. Such a break is in accordance with the relations of these two groups at the northern and southern limits of the area, where the Upper Llandovery overlaps the Lower.

No fossils have been found in the 'Tarannon Shales'; and the exact horizon of the lowest Wenlock rocks being unknown, it is not possible to determine whether these shales represent the highest horizon of the Valentian Series.

VII. North Wales: Corwen and Glyn Ceiriog.

Another district where both graptolitic and shelly fossils have been obtained from the Valentian rocks is that along the northern flanks of the Berwyn Hills in the Corwen and Glyn Ceiriog areas, where they have been described by Dr. T. T. Groom & Mr. P. Lake,[1] and still more recently by Dr. L. J. Wills,[2] and by him and Mr. B. Smith.[3]

The general succession of the Valentian and their relation to the adjoining rocks in the two areas, as described by Groom & Lake, is as follows:—

Corwen.	Glyn Ceiriog.
Denbighshire Grits.	Denbighshire Slates.
Pale Slates.	Ty-draw Slates.
Graptolite Shales (*gregarius* zone). Grey Slates.	Fron-Frys Slates.
Corwen Grit.	Glyn Grit and Limestone.
Blue Slate with Bala fossils.	Dolhir Beds.

[1] Q. J. G. S. vol. xlix (1893) p. 426; and *ibid.* vol. lxiv (1908) p. 546.
[2] Proc. Geol. Assoc. vol. xxxi (1920) p. 1.
[3] Abs. Geol. Soc. 1920–21, No. 1064, pp. 34–35.

Wills & Smith divide the Valentian Series into Llandovery or Birkhillian and Tarannon. The Corwen Grit was formerly considered to be the base of the Llandovery, and all the strata up to the Denbighshire Grits (Wenlock) were referred to that formation. At Glyn Ceiriog the fauna of the Glyn Grit was believed to indicate closer affinities with the underlying Dolhir Beds (Upper Bala) than with the Fron-Frys Slates. In the later description of the area these grits are assigned to the Ordovician.

Whatever may be their relations, there is no doubt that the succeeding Grey Slates of Corwen correspond generally to the Fron-Frys Slates. In the former district they are associated with a band of graptolitic shale, but contain in addition a sparse shelly fauna in their lower layers. At Glyn Ceiriog the graptolitic band was not found, though shelly fossils are abundantly represented.

The Pale Slates of the one district are similar in lithological character to the Ty-draw Slates of the other, and the two formations are believed to be equivalent.

The graptolitic shales have yielded a fauna which appears to indicate a horizon in the upper part of the *Monograptus-triangulatus* Zone or the succeeding *Mesograptus-magnus* Zone; that is, nearly the same horizon as the shales above the Newlands and Woodland Beds of Girvan. Wills & Smith record, also, the zones of *Monograptus cyphus* and *M. convolutus*. An approximate superior limit to the Grey Slates is thus given by reference to the graptolitic scale.

By the kindness of Dr. Groom & Mr. Lake I was allowed to examine their collection of fossils from the Fron-Frys Slates soon after the publication of their paper, and was able to confirm in essential particulars their determinations. The brachiopods from the area collected by the officers of the Geological Survey were also examined. The fauna is rather poor in species: the characteristic forms are *Barrandella undata*, like the Haverfordwest form, *Atrypa marginalis*, *Meristina subundata*, early variants of *Plectambonites duplicatus*, small species of *Dalmanella*, and a few Strophomenids. This fauna can be matched very closely in the *Barrandella-undata* or Cartlett Beds of Haverfordwest and the lower part of the Gasworks Mudstones; but the characteristic fauna of the upper part of those mudstones does not appear to be represented. It may be suggested that they, as well as the succeeding Gasworks Sandstone, are equivalent to the graptolite-shales of the Corwen area.

In the Ty-draw Slates Groom & Lake only found *Monograptus marri*, but further work by the Geological Survey has resulted in the discovery of the four main zones of the Tarannon district. The upper part of the Birkhill is not represented, its absence being attributed to a non-sequence.

In the Welshpool district graptolitic horizons are also intercalated among sandstones and conglomerates with shelly fossils. The relations between some of the groups attributed to the Valentian indicate an unconformity within the series. In some localities

fossils which are elsewhere distinctive of Lower or Upper Valentian are recorded from the same strata. The faunal relations are, therefore, too obscure at present to allow of a correlation with other districts being made.

VIII. Other Areas.

The remaining areas of Valentian rocks have this in common, that no recognizable equivalent of the Lower Llandovery Group has been proved. Where the base of the series is exposed, it rests on various older rocks ranging from the Pre-Cambrian to the Caradocian. In other areas the base is not exposed; but the evidence of surrounding districts leads to the inference that the Silurian rests unconformably on the lower rocks.

The development is subject to marked variation in thickness and faunal characters which has commonly been accounted for by regarding it as a littoral facies of the series. This appears to be a sufficient explanation. On faunal grounds we may recognize two sub-facies which have different geographical distributions: (1) The *Pentamerus oblongus* sub-facies, marked by the great abundance of that species, and characteristic of the Caradoc, Presteign, Builth, Woolhope, Malvern, May-Hill, Lickey, and Rosemarket districts. (2) The *Stropheodonta compressa* sub-facies, which includes the remaining areas of the South-West of England and South Pembrokeshire; namely, Tortworth, the Mendips, and the Marloes-Wooltack district. The boundary between these two facies is sharply defined in Pembrokeshire, where they are not more than 3 to 4 miles apart, and ranges thence almost due east and west, between Tortworth and May Hill. On geographical grounds another classification of the littoral development into a northern and southern sub-facies is thus possible. It is a fact of considerable interest that the contemporaneous volcanic eruptions are confined to the area of the southern sub-facies.

(1) The *Pentamerus oblongus* or Northern Sub-Facies.

This is most typically represented in the Caradoc region, where, as also at Builth, its relation to the Wenlock Shale can be observed. In each district a thin group of green and purple shales (or black, as at Builth) intervenes between the abundantly fossiliferous sandstones and the Wenlock Shale. In Pembrokeshire the Rosemarket Stage is overlain uncomformably by Old Red Sandstone, and no younger rocks are exposed in that inlier. Throughout most of the remaining districts the Valentian rocks pass up conformably into a calcareous group called the Woolhope Limestone, which is generally assigned to the Wenlock Series.

The usual associates of *P. oblongus* in these areas are *Atrypa reticularis*, *Cœlospira hemispherica*, *Schuchertella pecten*, and *Plectambonites*—also usually *Stricklandinia lens* and *S. lirata*. These are common forms in the Millin Stage of Haverfordwest and the Upper Valentian of Girvan. *Stropheodonta compressa* usually occurs also. The purple shales have yielded a considerable

number of fossils in the Caradoc area (Onny River). Of these, *Meristina furcata* appears to be confined to the Upper Valentian, and a *Barrandella* sp. allied to *undata* also suggests Valentian rather than Wenlock affinities. Most of the other forms, especially the trilobites, are either of uncertain affinities and unknown range, or occur indifferently both in the Valentian and in the younger rocks. The balance of the evidence furnished by their fauna and lithological characters inclines in favour of their Valentian affinities; but, from the very fact that they show such close relations to the Wenlock, they may be presumed to occupy faunally as well as stratigraphically a position at the very summit of the Valentian.

In the Presteign, May-Hill, and Malvern districts, the fauna of the sandstones is similar to that noted above; but at May Hill *Pentamerus oblongus* is much less abundant than in other districts, and the transition to the other facies may be presumed to occur not far south of this area. At Woolhope only the uppermost Valentian beds in which *P. oblongus* is not usually found are visible. The chief interest of these districts is the relation of the Valentian to the Woolhope Limestone.

At Old Radnor [1] that limestone lies unconformably on Longmyndian rocks, and is succeeded in normal succession by Wenlock Shale. The considerable faunal list quoted by Prof. Garwood & Miss Goodyear includes the following brachiopods, which denote a Wenlock age for this deposit:—*Meristina tumida*, *Barrandella linguifera*, *Conchidium knighti*, *Wilsonia wilsoni*, *Rhynchotreta cuneata*. They are associated with a few species of trilobites, among them *Illænus barriensis*, and a well-marked brachiopod, *Stropheodonta imbrex*, var. *semiglobosa*.

The supposed Woolhope Limestone at Nash Scar, Presteign, is considered to be contemporaneous with that of Old Radnor. In that district, however, it overlies the *Pentamerus-oblongus* Grits. Sedgwick [2] records from these grits the following forms:—*Cœlospira hemispherica*, *Pentamerus oblongus*, *Stricklandinia lens*, and *Spirifer crispus*.

At Woolhope the succession is described by Murchison [3] as follows:—

	Shales with bastard limestone.
Woolhope Limestone.	Purer limestone. Shales with bedded limestone up to 10 feet. (A total thickness of 30 to 40 feet of limestone.)
	Impure earthy limestone. Shales with calcareous gritty flagstones, with large *Stricklandinia lirata*.
Upper Llandovery ...	Greenish earthy calcareous sandstones, with *Stricklandinia lens*, etc.

The lowest bed contains *Stricklandinia lens*, *Atrypa reticularis*,

[1] E. J. Garwood & E. Goodyear, Q. J. G. S. vol. lxxiv (1918) pp. 1–29.
[2] Phil. Mag. ser. 4, vol. viii (1854) p. 476.
[3] 'Siluria' 5th ed. (1872) p. 111.

etc., and is attributed to the Llandovery Group. The shales with the calcareous bands assigned to the Woolhope Limestone yielded *Illænus barriensis*, *Homalonotus delphinocephalus*, *Spirifer elevatus*, *Stropheodonta imbrex*, *Schuchertella pecten*, *Plectambonites transversalis*, *Wilsonia wilsoni*, etc. Two of these forms are common to the limestone of the Old Radnor district, and the whole aspect of the fauna is Wenlockian. The systematic position of the shales with calcareous flags and the overlying earthy limestone is not clear from Murchison's description. He apparently regarded them as passage-beds from the Upper Llandovery into the Woolhope. Their chief interest is in the occurrence of the well-marked species *Stricklandinia lirata* (forma typica), which appears to be of very restricted vertical range. As there is no information in regard to the fauna associated with that species, it is impossible to decide whether the horizon should be attached to the Woolhope or to the Llandovery (see Marloes Bay, below).

In the Malvern area J. Phillips[1] describes the gradual passage from the Upper Llandovery rocks, with the usual fauna, into a group of shales with calcareous beds containing a somewhat different fauna, among which the following forms suggest Wenlock affinities:—*Anastrophia deflexa*, *Spirifer crispus*, and *Atrypa reticularis*, var. *linguifera*. *Stricklandinia lirata* is not recorded.

(2) The *Stropheodonta compressa* or Southern Sub-Facies.

This is exhibited in the Marloes-Wooltack area, Tortworth, and the Mendips.

As the relation of the Valentian to the succeeding rocks is clearly displayed in the former area, it will be referred to first. These sections are fully described in the Geological Survey Memoir.[2] The undoubted Valentian rocks are associated with contemporaneous volcanic products, and are distinguished by the abundance of *Stropheodonta compressa*, *Cœlospira hemispherica*, and Rhynchonellids, together with *Meristina furcata* and *Atrypa reticularis*, all of which are Upper Valentian forms. The occurrence of *Phacops stokesi* or a closely-allied form suggests a high horizon in the series, that species being more especially characteristic of the Wenlock Series.

These are succeeded at Wooltack by relatively-barren green and red grits and shales, with some appearance of unconformity at the base of the red grits. They are overlain by mudstones with a highly-distinctive fauna: *Palæocyclus* sp., *Barrandella globosa*, *Stricklandinia lirata* (forma typica), *Spirifer radiatus*, and *Atrypa reticularis* being extraordinarily abundant, and the assemblage appears to denote a high horizon in the Valentian. The *Stricklandinia* is indeed identical with the form which occurs at the base of the Woolhope Limestone of Woolhope.

[1] Mem. Geol. Surv. vol. ii (1848) pt. 1, p. 73.

[2] 'Geology of the South Wales Coalfield: Part XII—Milford' Mem. Geol. Surv. 1916, pp. 51–77.

At a higher level *Spirifer elevatus* makes its appearance in association with *Horiostoma sculptum* and Strophomenids, the whole being strongly suggestive of a Wenlock age. These forms are associated, however, with rare examples of *Barrandella globosa* and *Stricklandinia lirata. Palæocyclus* no longer occurs; but in Marloes Bay it is found in association with *Spirifer elevatus.* This horizon may be taken to indicate the overlap of the Valentian and the Wenlock fauna, and (together with the underlying *Stricklandinia* Beds) may be correlated with the Woolhope Limestone and the few feet of strata that immediately underlie it. Such a correlation had already suggested itself to J. W. Salter and Sir Henry De la Beche during their original survey of this coast.

An interesting comparison may be made with the Tortworth [1] area, where two 'trap-bands' are intercalated among fossiliferous calcareous sandstones. The brachiopod fauna includes the following forms:—*Cœlospira hemispherica*, *Atrypa reticularis*, *Stropheodonta compressa*, *Spirifer elevatus*, *Stricklandinia lens*, *S. lirata*, and in addition *Palæocyclus præacutus* and *Horiostoma globosum* (=*sculptum*). The general similarity of this fauna to that of the Wooltack-Marloes area at, and just below, the base of the Wenlock Series is evident; but in the Tortworth district forms are associated together which in Pembrokeshire are more widely spaced out.

It is interesting to observe that the beds above the upper 'trap' contain *Palæocyclus præacutus* in abundance, associated with *Stricklandinia lirata*, *Spirifer elevatus*, and *Horiostoma globosum* —an assemblage which is identical with that of Wooltack and Marloes. Unfortunately, the name *lirata* has been applied to most ribbed forms of *Stricklandinia*, and it is not known whether the one recorded is the typical form.

At Tortworth these occur with *Stropheodonta compressa* and *Cœlospira hemispherica,* which in Pembrokeshire are restricted to a lower horizon. On the other hand, *Meristina tumida* and *Spirifer crispus,* which are found with them at Tortworth, are characteristic of the Wenlock in Pembrokeshire.

The rocks between the two 'trap-bands' contain *Cœlospira hemispherica*, *Stropheodonta compressa*, *Stricklandinia lirata*, together with *S. lens*. *Spirifer crispus* is also recorded, as well as *Horiostoma globosum*.

It is possible that only a small time-interval is represented by the Tortworth rocks, and that they may be regarded as lying wholly within the horizon of overlap between the Valentian and the Wenlock: that is, the strata lying at the base of, and immediately underneath, the Woolhope Limestone.

These comparisons establish the fact that the rocks of the shelly facies which have commonly been assigned to the Upper Llandovery are equivalent generally to those which may be proved to be of Gala or Upper

[1] C. Lloyd Morgan & S. H. Reynolds, Q. J. G. S. vol. lvii (1901) p. 267; F. R. C. Reed & S. H. Reynolds, *ibid.* vol. lxiv (1908) p. 512.

CLASSIFICATION AND CORRELATION OF THE VALENTIAN.

Series	Valentian (Llandovery).		
Stage	Lower Valentian. Birkhill (graptolitic facies). Lower Llandovery (shelly facies).	Upper Valentian. Gala (graptolitic facies). Upper Llandovery (shelly facies).	Woolhope, Wenlock, or Salopian.
Sub-stage	Lower Birkhill. / Middle Birkhill. / Upper Birkhill.	Lower Gala. / Upper Gala.	
Graptolite Zones (see Table, p. 153).	*Persculptus.* / *Acuminatus.* (? *Modestus.*) / *Atavus.* / *Acinaces.* / *Cyphus.* / *Triangulatus.* / *Magnus.* / *Leptotheca.* / *Convolutus.* / *Sedgwicki.* / *Halli.*	*Maximus.* / *Turriculatus.* / *Crispus.* / *Griestonensis.* / *Crenulatus.*	
Districts. Girvan.	Newlands Stage. Mulloch Hill Group. Newlands and Woodland Groups. Saugh Hill Group. ?	Daily Stage. Camregan Group. Penkill Group. Bargany and Drumyork Groups.	
Haverfordwest.	Haverford Stage. Basal Group. Cartlett Group. Gasworks Mudstone. Gasworks Sandstone. Barren Shales. ?	Millin Stage. Uzmaston Group. Canaston Group. Concealed.	
Llandovery.	Lower Llandovery. Basal Group. Lower Division. Upper Division. Absent?	Upper Llandovery. Absent? *Oblongus* Mudstone. *Oblongus* Sandstone. Purple & Green Group.	
Corwen, etc.	Fron Frys Slates. Absent.	Pale Slates. ?	
Shropshire.	Absent.	Absent? *Oblongus* Group. Purple & Green Group.	
Woolhope, Wooltack, etc.	Absent.	Absent? *Compressa* Group. *Lirata* Group.	

Valentian age by direct reference to the graptolitic scale.

At Haverfordwest, the only district outside Girvan where the lowest-known Upper Llandovery rocks exist, the base of the Uzmaston Group coincides with the base of the Gala. We have seen, also, that in the southern areas comprising Woolhope, May Hill, Malvern, Marloes, and Wooltack, the highest Upper Llandovery rocks are succeeded conformably by the lowest Wenlock rocks or their representative, the Woolhope Limestone. Elsewhere, especially in the Caradoc and Llandovery districts, a thin band of greenish shales intervenes between the Upper Llandovery and the base of the Wenlock; but the affinities of those shales link them with the underlying beds, and they are probably represented in the districts previously mentioned by calcareous sandstones indistinguishable from the ordinary Upper Llandovery type. They may, therefore, be grouped with the underlying rocks as a special local development. If this be done, then the upper limit of the Upper Llandovery is defined by the base of the Wenlock, as, in fact, is the upper limit of the Gala Stage. Thus both upper and lower limits of the Upper Llandovery, where fully represented, coincide with those of the Gala Group.

Dame Ethel Shakespear's investigations showed that the Tarannon rocks of Tarannon as redefined were also equivalent to the Gala rocks, including the Hawick subdivision, and are therefore of the same age as the Upper Llandovery shelly rocks, so that the classification of the Upper Valentian into Upper Llandovery + Tarannon is without meaning. Until the Tarannon area was revised, the chief purpose of the term was to denote a group of purple and green shales which underlay the base of the Wenlock, and it was coupled with Llandovery in order to make clear the intention to include all the rocks up to the base of the Wenlock.

Now that it has been proved to be equivalent to the Gala on the one hand and to the Upper Llandovery on the other, a more homogeneous classification of the graptolitic and the shelly facies of the Valentian is obtained by dropping this term, which has been the source of so much confusion, and reverting to the older-established Birkhill-Gala, and Lower and Upper Llandovery respectively. The Tarannon area will, however, always be known by reason of the clear succession therein displayed, and of Dame Ethel Shakespear's classic researches upon the rocks and their fauna.

The foregoing conclusions are summarized in the accompanying table (p. 170). Here the space allocated to each graptolitic zone in the Lower and the Upper Valentian respectively is proportional to its thickness, in a given district. It is found that, although the actual thickness of the zones varies greatly from one locality to another, their relative proportions remain approximately the same. It is not known, however, whether the thickness of a given zone bears any strict relation to the length of time involved in the

formation of the sediments. It may, in fact, be argued that a thin band of graptolitic shale has taken longer to form than the intervening non-graptolitiferous strata. In the accompanying table the zones comprise the shale-bands containing the zone-fossil, as well as the other sediments which occur above, below, or between these bands; and for this reason it may be assumed with some probability that, where the conditions of deposition have remained tolerably uniform, as in the Birkhill Period, that the thickness of a zone bears some proportion to the length of time which elapsed during its formation.

It cannot be assumed, however, that the conditions of deposition which prevailed during the Birkhill Period persisted into the Gala Period. On the contrary, it is certain that a considerable change of physical conditions occurred between the two periods. The space allotted to the Upper Valentian is therefore made arbitrarily equal to that of the Lower Valentian, and subdivided among its five zones in the proportion of the thickness of these in the Tarannon area.

An important fact which emerges from the table is that in all districts where the shelly facies prevails there is no evidence of a transition from the Lower to the Upper Valentian; but, on the other hand, there is every indication of a physical break at this horizon.

IX. The Base of the Valentian.

Since it is now agreed to include the whole of the Valentian Series in the Silurian, it becomes important to define as accurately as possible the base of that series. As previously mentioned, Aveline attempted to draw a line separating the Lower Llandovery rocks from the Bala; but he was unsuccessful, and for the shelly facies this was first accomplished by J. E. Marr & T. Roberts [1] in the Haverfordwest district, where they recognized a group of conglomerates and sandstones underlying the fossiliferous Gasworks Beds, and probably representing their basal members. This was confirmed by the officers of the Geological Survey during the re-examination of the area around Narberth and Haverfordwest, and by the aid of these beds the base of the Silurian in that area was mapped in detail.

No unconformity was detected between the Silurian and the Ordovician. The fossiliferous Slade Beds (Ordovician) are succeeded in some sections by a group of dark shaly mudstones which are overlain by a grey sandstone. In others a conglomerate of varying thickness is associated with the mudstones, occurring in places within them and in others at their base. It is only in the latter case that the base of the Silurian can be accurately located. In Girvan that horizon is defined by massive conglomerates (Mulloch Hill, etc.) below which there is probably an unconformity and overstep. In the Moffat area the base of the Birkhill was drawn by Charles Lapworth at the bottom of a peculiar band

[1] Q. J. G. S. vol. xli (1885) p. 476.

underlying the *Acuminatus* Zone, consisting of

'tough slightly calcareous shale weathering of a brownish drab, or gingerbread-colour ("the gingerbread band"), and affording numerous examples of *Climacograptus scalaris* (var. *normalis*) in a state of high relief.' [1]

This horizon coincides with a marked palæontological break in the succession.

In the Lake District, J. E. Marr & H. A. Nicholson [2] describe two different types of deposit at the base of the Valentian (Stockdale Shales). In Skelgill Beck and other localities about 1 foot of a tough impure limestone of a mottled appearance, and containing a considerable quantity of iron pyrites, overlies the Ashgill Shales: in it was found *Atrypa flexuosa*. The relation of this to the overlying Lower Birkhill Shales is nowhere seen. In Browgill 2½ feet of mottled, pyritous, calcareous shale occurs at the base, and is considered from its close lithological resemblance to represent the *Atrypa-flexuosa* Limestone. It yielded *Diplograptus acuminatus* and *Climacograptus normalis*. These authors refer to a complete palæontological break between the Lower Skelgill Beds and the highest Ashgill Shales, although there appears to be perfect conformity in dip and strike between the two formations.

At Austwick the base of the Silurian is a fossiliferous conglomerate, which appears to mark a physical break of some importance.

At Rhayader the base of the Silurian was drawn on lithological grounds below a great zone of grits (Gwastaden Grits), which are followed conformably upwards by graptolitic Birkhill Shales, but rest abruptly upon very dissimilar strata assigned to the Bala. In all the areas so far noted the lowest graptolitic zone recorded is that of '*Diplograptus*' *acuminatus*.

In Central Wales I gave reasons [3] for assigning the basal beds of the Birkhill Group to a new zone, *Glyptograptus persculptus*, which underlies the *Acuminatus* Zone. The new zone consists of blue-grey, dark-flecked or mottled, tough, compact mudstones, in places slightly calcareous and in others containing a considerable quantity of iron pyrites: they tend to weather snuff-brown. The description of these strata recalls at once both the 'gingerbread band' of Moffat and the basal beds in the Lake District. The zone-fossil occurs in profusion in a shale-band close to the base of the zone. The boundary between these deposits and the Ordovician has been examined at many localities over an area of about 200 square miles, and is always sharply defined. The overlying rocks can in many places be stripped off, revealing a smooth, slightly-undulating surface of the Bala rocks. There is no appearance of a passage between the two formations, and, on the other hand, no sign that the sharp demarcation between them is the result of movement at the junction.

The type of Bala in contact with the base of the Silurian is not everywhere the same; but in such unfossiliferous sediments it is

[1] Q. J. G. S. vol. xxxiv (1878) p. 252. [2] *Ibid.* vol. xliv (1888) p. 654.
[3] *Ibid.* vol. lxv (1909) p. 482 & vol. lxxi (1915–16) p. 350.

possible to attribute these differences to variation within that formation, although this may not be the true explanation.

The resemblance of this group in lithological characters and mode of weathering to the much thinner band which occurs at the base of the Silurian in the Lake District and Moffat, and its position with respect to the *Acuminatus* Zone, renders it probable that the zone-fossil may yet be found in the very lowest part of the Silurian in the northern districts. Its common associate, *Climacograptus normalis*, preserved as in Central Wales in high relief, has already been noted in that position. It is satisfactory to find that the zone-fossil occurs in a shale-band between the grits of Gwastaden near Rhayader, not many feet above their base. The horizon adopted by Dr. Herbert Lapworth on lithological grounds agrees, therefore, with that proposed above for faunal and physical reasons.

It is probable that the abrupt lithological change at the base of the Silurian in all areas is the result of a change in the physical conditions of deposition, which appears to have brought about a marked palæontological break. The mottling of the basement-beds, which is due to the inclusion of clots and flecks of a dark mudstone among the pale sediments, and the high content of pyrite are suggestive of arrested sedimentation, if not, also, of actual erosion.

Discussion.

Dr. H. Lapworth congratulated the Author on his paper, and on the fresh data that he had brought forward regarding this puzzling series. From his own knowledge the speaker agreed that the name 'Tarannon' was vague, but so was 'Llandovery'; and he felt that, until further research was carried out in the Llandovery district itself, and more detail had been secured from the Corwen–Cerig-y-druidion area, any restriction in nomenclature might lead to controversy. The speaker's own view of the Valentian was that deposition appeared everywhere in Britain to be continuous from the *Persculptus* Zone, or base of the Silurian, up to at least the *Convolutus* Zone. At or immediately above this horizon there may or may not have been local elevation and a break for a time; but great depression apparently continued for the remainder of the Valentian Period, so that one might find any of the succeeding zones as the base of the series resting upon older rocks.

The Author thanked the Fellows for their kind reception of the paper, and in reply to the previous speaker stated that an account of the succession in the Llandovery area was included in the paper. Although the structure of that area was still imperfectly known, sufficient was known of its fauna to make a correlation with other districts possible. The Author hoped at an early date to resume the mapping of that district, which had been interrupted by various circumstances for many years.

[August 19th, 1921.]

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Session 1921–1922.

1921.

Wednesday,	November	23
,,	December	7 —21*

1922.

Wednesday,	January	4*—18*
,,	February (*Anniversary Meeting*, Friday, February 17th)	1*—22*
,,	March	8 —22*
,,	April	12
,,	May	10*— 24
,,	June	14*—28

[*Business will commence at 5.30 p.m. precisely.*]

The asterisks denote the dates on which the Council will meet.

8. *The* CHAROPHYTA *of the* LOWER HEADON BEDS *of* HORDLE [HORDWELL] CLIFFS (SOUTH HAMPSHIRE). By CLEMENT REID, F.R.S., F.L.S., F.G.S., and JAMES GROVES, F.L.S. (Read November 22nd, 1916.)

[PLATES IV–VI.]

PREFATORY NOTE.

[The first part of this paper, written by the late Clement Reid, was communicated to the Society very shortly before his death. It may be taken as the latest expression of his views upon the position of the Lower Headon Beds of the Hordle Cliffs, arrived at by the study of these beds during the last four years of his life, when he resided at Milford-on-Sea. Except for a few verbal corrections, the paper is given as he left it.

The Charophytic remains, nearly all collected by him, had been discriminated and partly classified before his death, but the descriptions had not been written.

It will be noted that some of his statements refer to the difficulty or impossibility of comparing specimens from other areas. This is due to the fact that, when he wrote, the War was still in progress. The same cause led to delay in publication of the paper, for it was deferred in the hope of obtaining further information as to the remains occurring in the Paris Basin; but, unfortunately, this has not been found possible.—E. M. REID & J. GROVES.]

PART I.

THE correlation of limestone-deposits lying in isolated basins has always been a matter of much difficulty and uncertainty. Thus far no group of freshwater fossils has proved sufficiently widespread and characteristic for the purpose of zonal work. The mammals have a very limited geographical range, their assemblage depends so largely on the nature of the surrounding country, and their remains are usually so scarce, that they do not greatly help; besides which, in strata older than the Tertiary they almost fail us. Other vertebrates, such as fishes, would also vary greatly in adjoining areas.

The freshwater and brackish-water mollusca, which are so abundant, and would at first sight appear so useful, cannot be depended on for the comparison of distant areas. Many of the species are very local, and their variation under slightly changed conditions is so great as to give rise to much confusion. Anyone who has worked with the genera *Unio, Corbicula, Cyrena, Paludina, Melania, Potamides,* or *Limnæa* in the London and Paris Basins must have felt this difficulty. In the case of the nonsculptured genera, such as *Paludina,* the difficulty is increased by a tendency to vary around a certain generic type, to which the species seem to revert again and again. Indeed, in certain of the molluscan genera the specific differences are so slight as only to be recognizable in specimens better preserved than such as are commonly available.

The higher plants are usually very local, and their remains are

too rare in most strata to be of much assistance. For the correlation of far-distant deposits we need some group of fossils easily dispersed, and therefore widely spread, having many generic and specific forms of limited range in time, with specimens occurring in profusion in a determinable state. In short, for zonal work in freshwater strata we require a group somewhat equivalent to the graptolites in wide distribution and characteristic forms.

One group seems to possess all these qualities, if we can obtain sufficient material. The Charophyta are submerged aquatic plants, of which the living genera and species have generally wide ranges, and the peculiar fruits with their spirally-coiled cells offer many characters for specific determination. They usually occur in profusion in the places where they grow, and they grow nearly everywhere in pools, lakes, and brackish-water lagoons. The fruits, being commonly calcified, are found in most deposits that contain freshwater mollusca: in fact, many of the so-called 'shell-marls' would be more properly described as '*Chara* marls.'

Though for many years the fossil Charophyta have been gathered from various freshwater deposits, it was not until one of us settled in Hampshire, and began to collect more fully the plants of the Hordle Cliffs, that the idea of using Charophyta as zone-fossils took shape. A slight search showed that in these Tertiary strata there were many unknown forms, some apparently of peculiar generic types. Concurrently with this work on the Tertiary species, we undertook the examination of the Purbeck Charophyta, with the result that the various Purbeck forms seem all to belong to strange extinct genera. The Swiss Miocene and the Austrian Lower Eocene forms, only as yet slightly examined, seem also to belong to well-marked groups of limited vertical range.

These indications of the value of the group for the purposes of zonal work, combined with the discovery in a short time of so many undescribed types, has induced us to undertake the working-out of the Charophyte flora of the zone most thoroughly searched—the Lower Headon Beds. We should like to have investigated the whole of the Hampshire-Basin Eocene and Oligocene deposits, also to have established the correlation of the freshwater strata with those of the Paris Basin; but the War made it impracticable to get about in certain areas, and also made it impossible to consult the foreign museums, especially those of Paris.

In the Hordle Cliffs of the mainland of Hampshire, the strata below the superficial gravel belong certainly to the Lower Headon Series: a small outlier of the marine Middle Headon, formerly seen, having now been entirely destroyed by the encroachments of the sea. There is no possibility, therefore, that any of our specimens can have come from any but this one horizon. The Headon Beds, though placed by British geologists, following Judd, in the Oligocene, and lithologically more closely allied to the Oligocene above than to the Barton Beds below, are in reality on the same horizon as the Calcaire Grossier of the Paris Basin, and this for

some time has been recognized. As the Charophyta also, so far as they can yet be compared, lead us to the same conclusion, we shall not hesitate to speak of the Headon Beds as Upper Eocene.

The strata seen in Hordle Cliffs consist throughout of fresh-water and brackish-water deposits, more or less calcareous, laid down in wide shallow lakes and lagoons, precisely the conditions in which Charophyta best flourish. The flora, therefore, is rich and varied; and this one deposit has already yielded many more species than the whole of the British strata were known to contain. Although so many species occur, there is no reason to consider that the Lower Headon strata belong to more than a single zone. There are slight differences in the species contained in different seams; but nearly all of them have now been found in the thin seam of limestone, which (of all the beds) has been most thoroughly searched.

An excellent account of the succession of the beds in Hordle Cliffs was published by E. B. Tawney & H. Keeping in this Journal,[1] and we cannot do better than use their numbering of the beds, although in some cases botanical work might induce us to subdivide differently these variable and impersistent strata. The total thickness of the Lower Headon strata is given by them as $83\frac{1}{2}$ feet, and we do not think this measurement far wrong.

It should be remembered that for Charophyta the ordinary carbonaceous plant-beds are not suitable from the point of view of preservation, for calcareous fossils usually tend to decay in the presence of much vegetable matter. Shaly beds also are bad conservators, for any crushing of the specimens makes it impossible to extract the Charophyta in a recognizable state, though we may be able to note the deposit as largely made up of these plants. Charophyta are best preserved in the soft limestone, in the shelly beds, or in sandy seams which have resisted compression.

Our search for these plants in Hordle Cliffs has been conducted systematically, and they prove to be far more generally diffused than the published accounts would suggest. As a rule, however, each seam or lenticle yields only two or three species, and, in order to avoid spending time unprofitably in washing large quantities of such material, work latterly has been concentrated on a few very prolific seams in which the Charophyte flora has proved to be exceptionally varied.

The lowest beds of the Headon deposits (Nos. 1 to 7 of Tawney & Keeping) are carbonaceous clays, not good receptacles for Charophyta. Then follows a conspicuous band of big ironstone-nodules (No. 8), which will enable the geologist to fix his position. Next follow $12\frac{1}{2}$ feet of bluish and greenish clays, with seams of sand (No. 9). This is commonly known as the Mammal-Bed, for most of the larger mammalian remains have been found in it,

[1] 'On the Section at Hordwell Cliffs, from the Top of the Lower Headon to the Base of the Upper Bagshot Sands' Q. J. G. S. vol. xxxix (1883) pp. 566–74.

though of late years finds have been rare. No. 9 is also full of small lenticular seams of sand, some of which are crowded with fruits of *Chara*. Several of these little seams have been washed, and the following species have been found:—*C. Wrightii*, *C. vasiformis*, *C. helicteres*, *C. tornata*, and *C. subcylindrica*. Possibly these little sandy lenticles in the clays point to the washing-together of the comparatively heavy Characeous fruits into shallow channels during exceptional floods or storms, for the rest of Bed 9 suggests very tranquil deposition.

No. 10, the 'Basement Seed-Bed' including the 'Leaf-Bed,' is noted by Tawney & Keeping as a variable series of deposits. At the top is a carbonaceous clay with rootlets, below a lenticle of lignite varying from 9 inches in thickness on the east to 12 feet where it crops out under the gravel at Long Mead End; and under this is some green clay with ironstone slabs penetrated by small roots. Recent exposures show it to be even more variable than is stated: for in one place it is strongly current-bedded; in another it is channelled, and shows a local development of seams of grey calcareous loam, full of seeds of aquatic and terrestrial plants. These 'seed-beds' have lately been carefully searched for their plants, which include several undescribed species; but fruits of Charophyta are comparatively rare, and, as is usual in carbonaceous deposits, tend to go to pieces. The species obtained were:—*C. Wrightii*, *C. cælata* var. *baccata*, *C. vasiformis*, *C. tornata*, and *C. subcylindrica*. The 'leaf-beds' on the same horizon, but more conspicuously developed farther west, are full of fragments of a pinnate-leaved palm, of a cinnamon, and of fronds of a tropical fern, *Chrysodium*; in them Charophyta do not occur in a determinable state.

Beds 11 to 13 were sampled, but yielded no *Chara*, and the same was the case with Bed 14 (the 'rolled bone-bed' of Tawney & Keeping). Above this comes Bed 15, a 7-foot mass of fine silty sands, with thin loamy seams and conspicuous bands of *Potamomya* and a few other brackish-water shells. The shells are mostly tender and fragile, and it was very difficult to preserve the *Chara*-fruits found in the sand; but, after some of the clay-partings had been washed, two species were obtained. Bed 15 is evidently a lagoon deposit of brackish-water origin; it is the principal source of the crocodile-remains.

Bed 16 is a mass of green clay, with a conspicuous band of big ironstone-nodules; at its top is a seam of lignite. We do not happen yet to have met with any of the thin seams full of *Chara*-fruits, which are usually to be found in clays of this character; and Bed 17 is so much more promising, that it was thought better to devote the time available to its more thorough investigation.

Bed 17 is a conspicuous band of soft cream-coloured limestone, varying from 3 to 7 inches in thickness, and occurring almost exactly in the middle of the Lower Headon Series. Though so

thin, it is easy to find, for it makes a distinct ledge, and is the only limestone now left in Hordle Cliffs. It crops out under the gravel at Long Mead End, and sinking eastwards must descend to the sea-level near the first steps to the beach, though talus still hides this part of its outcrop. The part of the cliff in which this limestone appears, after being for several years much obscured by talus, has lately been much better exposed. The limestone is full of *Limnæa* and *Planorbis*, and seems to be purely of freshwater origin. At its hardest it is a soft stone, and much of it is so marly as to go to pieces if dried and then placed in water. It is full of fruits of *Chara*, and has yielded a more varied Charophyte flora than any other of the Headon Beds. This is partly due to its real productiveness, partly to the much greater attention paid to it when its productiveness was discovered.

The best pieces to select for washing in this limestone are the fairly hard lumps in which the mollusca are not much distorted, for the more marly and shaly parts will not bear washing without the fossils going to pieces. Though the bed only crops out for a short distance, it is well to take a number of samples, for some of the species of *Chara*-fruits drift into little pockets or nests, and have only been found at a single spot. In addition to the fruits, fragments of stems and branchlets belonging to several species have been found. Most of the Lower Headon Charophyta occur in this bed; but its flora is not quite so exceptionally rich as would at first appear, for some of its species are of extreme rarity, and have only been found through long-continued search. Only two of the fruits that we have named, occurring fairly commonly in the limestone, have not been found in any of the other beds—the exceedingly minute *Tolypella parvula*, and *Chara polita* With the latter fruit possibly may be associated the slender solidly-calcified stems and branchlets found in the same deposit (type A), though at present we cannot definitely associate any of the fruits with their corresponding vegetative parts.

The list of Charophyta found in the limestone is as follows:—*C. Wrightii*, *C. cælata*, with vars. *bicincta* and *baccata*, *C. vasiformis*, *C. polita*, *C. strobilocarpa* and var. *ellipsoidea*, *C. turbinata*, and *Tolypella parvula*; but, as several of the most peculiar forms are only represented by very few specimens, this list is probably by no means complete.

The next 14 or 15 feet of strata (Beds 18 to 27 ?) consist mainly of clays, not at present well seen, and therefore not thoroughly searched. They form a gentler slope above the ledge of limestone, and lead up to another white band, this one consisting of highly calcareous shelly sand, nowhere hardened into stone. This white band, only a few inches thick, is seen in the upper part of the cliff, just under the gravel, nearly opposite Hordle House; but it can best be examined where it caps the landslip at the top of the undercliff immediately below. It can be reached by descending the westernmost ladder, and then walking a short distance westwards

along the undercliff. [[1] The white band is an important horizon in the Headon Beds; but, unfortunately, it is the only one as to the correlation of which with Tawney & Keeping's section we feel in doubt. If it is their '*Chara* Bed' (part of No. 28), then the details now seen do not correspond with their measurements and description, and it is strange that a collector who has worked so long at these deposits, as did Keeping, should not have noticed the numerous small bones and teeth, mainly of rodents, which it contained. It is curious also that these authors should state that their *Chara* Bed is seen at Paddy's Gap,[2] but thins out westwards. The deposit that we have seen and collected from is well exposed, as already mentioned, on the west; but we think that it was sunk below the beach-level before Paddy's Gap is reached. At Paddy's Gap recent storms have entirely cleared the section, and thin lenticles crowded with fruits of *Chara* are seen in a matrix of blue or green clay; but they do not resemble or appear to be on the same horizon as our 'Rodent-Bed.' Probably the deposit is part of the series marked 4 in the Marchioness of Hastings's description,[3] for in this she found the small bones.

This part of the cliff, after being obscured by talus for many years, is now gradually being cleared again by renewed encroachments of the sea; but there is still a piece, from opposite the Hotel westwards to the last steps to the beach, along which the beds cannot be traced continuously, so that the exact details of this part of the section must remain in doubt. If we are right in thinking that the *Chara* Bed of Paddy's Gap is not the same as the Rodent-Bed, then it is probable that a few feet must be added to the total thickness of the series.]

From the Rodent-Bed, which is only a few inches thick, we have obtained several species of freshwater and brackish-water mollusca, a number of small mammalian bones and teeth, and several species of Charophytes. One minute subglobose fruit (*Tolypella headonensis*) is confined to this horizon, as perhaps are one or two other noticeable forms. The difference between the flora of this deposit and that of the limestone is, however, more likely to be due to the influence of varying amounts of salt, rather than to any great difference of date. The species found in the Rodent-Bed are:—*C. Wrightii*, *C. vasiformis*, *C. distorta*, *C. tornata*, *C. subcylindrica ?*, *C. strobilocarpa* var. *bitruncata*, and *T. headonensis*.

At its top the Rodent-Bed is cut off abruptly by a thin seam of black clay, perhaps Bed 29. Then follows a thick mass of green clay (Bed 30?), with occasional thin lenticles of drifted *Chara*-fruits. These seem to be the beds seen at the foot of Paddy's Gap (Mineway), close to the beach-level. The species are few, only

[1] The discrepancies referred to in the part of the text enclosed between square brackets are probably due to the fallen state of the cliff, which rendered observation difficult. [E. M. R.]

[2] Paddy's Gap is the gap leading to the shore opposite Rookcliffe. In older records it was known as 'The Mineway.'

[3] Bull. Soc. Géol. France, ser 2, vol. ix (1852) pp. 191–203.

Chara Wrightii, *C. helicteres*, and *C. vasiformis* being seen. Other fossils, except *Paludina* and *Unio*, are not common.

A conspicuous but thin sandy band crowded with seeds of *Limnocarpus* and *Stratiotes* is very noticeable east of Paddy's Gap. It has yielded also a few fruits of *Chara*, but they are not very well preserved.

Then follow thin bands of clay and sand, with *Paludina*, *Melania turritissima*, and *Unio*; in these we have not observed any Charophyta.

Bed 31 is the sand which now rises nearly to the top of the cliff under the gravel. It was formerly followed by a band of clay, and this by a thin limestone (32)—the How Ledge Limestone; but these two beds, together about 5 feet thick, have now entirely disappeared, as has the marine Middle Headon last seen about the year 1850.

Part II.

The remains of Charophyta, which afford the material for this paper, consist of numerous detached fruits, some fragments of stems and branchlets, and a few stem-nodes with portions of the internodes of stems and the bases of the branchlets attached. There are also a few bodies which are apparently the actual stem-nodes. In no instance has a fruit been found attached to a branchlet, and, owing to the fact that in each deposit more than one type of fruit is present, it is not possible to identify any of the fruits with the vegetative parts to which they belong.

Fruits.

The fruits, the remains of which are here preserved as fossils, would appear to consist only of those which have developed a 'lime-shell,' similar to that with which we are familiar in many existing species of *Chara* and in a few of the *Tolypellæ*. This lime-shell is formed by the secretion of carbonate of lime of extremely fine grain, in the interior of the five spiral cells which constitute the wall of the oogonium. As the fruit matures the lateral walls of the spiral cells, where they are in contact one with the other, break down, and the calcareous contents of the five cells combine to form one shell which surrounds the oospore. The calcareous deposit goes on increasing, until it has almost entirely replaced the original protoplasmic contents of the cells. That the preservation of these fossil fruits is due to the presence of the lime-shell may, we think, be fairly adduced from the following considerations:—

(1) The practical impossibility of large thin-walled cells being preserved in such a formation if merely filled with protoplasm.

(2) The fact that no evidently young fruits are found as fossils, and that in existing species the lime-shell only occurs in mature fruits.

(3) The invariable absence in the fossils of the coronula and stalk-cell, which organs, in existing species, do not secrete calcium carbonate.

(4) The great diversity in the thickness of the shell in the fossils, the

thinner being concave, the thicker flat or convex on the exterior, corresponding with the various stages in the development of the lime-shell of living species. The calcareous accretion forming the latter is built up by deposits on the concave inner wall of each spiral cell; hence in earlier stages, when it is thin, the whole lime-shell presents a series of ridges with rounded concave valleys between, which latter gradually fill up, until the whole space is occupied, and the valleys have been transformed into rounded ridges, while the former ridges have become furrows.

In the case of the fossil fruits, when they break up, the spiral portions separate most readily along their edges, long detached pieces of individual spirals being frequently found, and when these are fractured it is by a clean break transversely. When a recent lime-shell breaks, this is not usually the case, a fracture taking place more commonly quite irregularly across several spirals. This difference may be due to the fact that the lateral walls of the spiral cells, in the case of the Tertiary plants, do not break down so completely before calcification, as in the recent species, and the lime-shell, in consequence, is incompletely developed along the sutures.

We have found the oospore preserved in a few cases, mostly in the gathering from the Basement-Bed Owing to the non-preservation of the stalk-cell, there is an opening at the base of the oogonium which is referred to in the descriptions as *foramen basilare*. The walled-in space at the base of the oospore corresponding to this is styled *cohors basilaris*.

The fossil fruits are very diverse in shape, ranging from completely globular (Pl. IV, figs. 1–8) to elongated ellipsoid, elongated obovoid, and (Pl. V, figs. 4 & 5) subcylindrical. In size the diversity is also considerable, the length of those measured ranging from about 325 to 1200 μ, and the breadth from 250 to 1C50 μ. In colour, also, there is great diversity; but this doubtless is, to some extent, due to the conditions under which the fruits were preserved. Some of the types of fruit resemble those of living species.

In the lime-shell of existing species we have seen no approach to the remarkable papilliform processes found in some of the fossils, to the cause and nature of which we have not at present discovered any clue. The papilliform processes occur at more or less regular intervals along the spiral cells. They were apparently first observed by Sir Charles Lyell in fruits from the Bembridge Beds, described and figured by him in Trans. Geol. Soc. ser. 2, vol. ii (1826) p. 94, pl. xiii, figs. 7 & 8, under the name *Chara tuberculata*. Subsequent authors have described other species having similar processes. Dr. Guido Stache, in his fine monograph on the fossils of certain ancient Tertiary beds in the neighbourhood of Trieste ('Die Liburnische Stufe' 1889), describes and figures six species with this characteristic, and constitutes for them a section Kosmogyræ, placing them under two genera, *Kosmogyra* and *Kosmogyrella*.

Among living species there are none with fruits quite like the large globose and sub-globose types figured in Pl. IV, figs. 1–10.

The features essential to the satisfactory determination of the genera are, unfortunately, lacking in the fossil fruits. The types numbered 11 & 12, however, so closely resemble the fruits of living species of *Tolypella* that we think there can be little doubt that they are correctly placed under that genus. The rest have been provisionally retained under the parental generic name *Chara*, sufficient evidence not being available to place them under other genera, although there is every probability that some do not belong to the genus *Chara* in its restricted sense. It is probable that the large globular and broadly-ellipsoid fossil fruits, with swollen tips to the spiral cells suggesting a deciduous coronula, belong to a genus akin to *Nitellopsis*.

None of the fossil fruits that we have examined shows any sign of the longitudinal flattening characteristic of the genus *Nitella*.

The following types appear to us sufficiently distinct to justify their differentiation as species. Possibly some of those now referred to varieties may also prove to be distinct, especially when we consider the similarity of the fruits of closely-allied living species.

There are, in addition, a few fruits which we have not been able to refer with certainty to any of the types described, but which either appear insufficiently distinct, or for which there is insufficient material to justify the assignment of a name to them (Pl. VI, figs. 6-8).

The presence of so great a number of more or less distinct types in this series of beds is not surprising, in view of the number of living species sometimes found growing together in the same piece of water. In Hickling Broad (East Norfolk), for instance, Canon Bullock-Webster has collected twelve species of Charophytes; while M. Émile Gadeceau in his admirable monograph on the Lac de Grandlieu (near Nantes) records no less than seventeen species from that lake.

The measurements given here are those of well-developed fruits, the smaller specimens often present being ignored. Many imperfect fruits occur, and in such cases it is almost always the apex which is wanting. The thickness of the spiral cells is stated when broken specimens in which the calcareous shell seems to have attained its full development are available.

1. Chara Wrightii, Salter in Forbes, Mem. Geol. Surv. 1856, p. 160 & pl. vii, figs. 15–21. (Pl. IV, fig. 1.)

Oogonium fere globosum, latitudine quam longitudine plerumque majus, diametro c. 950–1100 μ; cellulæ spirales in statu maturitatis convexæ, latissimæ (c. 150–200 μ) et crassissimæ (c. 75–125 μ), leves vel nodulosæ, in apice, supra collum constrictum, plusminusve turgido, circ. septem convolutiones exhibentes; foramen basilare comparate parvum, cum conformatione variabili, plerumque paulo dilatum, interdum cum ore lato. [Oospora fere globosa, diametro c. 700–775 μ, liras humiles sex–septem exhibentes; cohors basilaris diametro c. 150 μ.]

Var. RHYTIDOCARPA nov. Cellulæ spirales eminentias inæquales et angulatas prætendentes. (Pl. IV, fig. 3.)

Var. MINOR nov. Oogonium cum conformatione formæ typicæ simili sed minus, diametro c. 750–850 μ. (Pl. IV, fig. 2.)

The fruits vary in colour from light yellowish to dark purplish-brown. When fully developed the spiral cells are convex; they are often much swollen at the apex, which is often a lighter brown, and the constriction at the neck is very marked. The form of the fruit differs from that of any living Charophyte, in that the breadth is often greater than the length. It may be conjectured that the plant belonged to a genus akin to *Nitellopsis*.

If not identical with *C. medicaginula* Brongniart, as suggested by J. W. Salter (*op. cit.*), there is no doubt that *C. Wrightii* is very closely allied to that species. The size of the fruits of the former given by W. Ph. Schimper, in his 'Traité de Paléontologie Végétale' vol. i (1869) p. 221 (1100–1150 μ), is somewhat greater than that of the Hordle plant. We have not had sufficient opportunity of examining the remains from the Paris Basin to form an opinion as to their identity.

The var. *minor* of *C. Wrightii* bears about the same proportion in size to the type as the var. *minor* of *C. medicaginula*. The form *rhytidocarpa* may be merely an abnormality; but we have seen similar specimens from the Lower Headon Beds of the Isle of Wight.

In the Basement (Seed)-Bed a number of the oospores are preserved within the oogonia; but, being very thin-shelled and brittle, they are difficult to handle. We have, however, been able to get out three specimens nearly entire, and from this rather meagre material the above description is drawn. A nearly globose oospore from the Limestone-Band, filled with the matrix, probably also belongs to this species. This is shown in Pl. IV, fig. 11.

C. Wrightii is the commonest Charophyte in the Hordle Beds, sometimes occurring in great numbers. It was obtained from the Mammal-Bed, the Basement (Seed)-Bed, the Limestone-Band, the Rodent-Bed, and the Mineway.

2. CHARA CÆLATA, sp. nov. (Pl. IV, figs. 4–6.)

Oogonium fere globosum, diametro c. 950 μ; cellulæ spirales latissimæ (c. 150–175 μ) cum ordine tuberculorum rotundato-conicorum, apice turgescente, circa septem convolutiones exhibentes; foramen basilare angustum, ore paulo dilato.

Var. BICINCTA. Cellulæ spirales ordine tuberculorum irregulariter duplicato. (Pl. IV, figs. 7 & 8.)

Var. BACCATA. Oogonium subglobosum quam idem formæ typicæ minus, diametro c. 850; tuberculi magni humiles rotundati; foramen basilare latius. (Pl. IV, figs. 9 & 10.)

In shape the fruit of this species resembles that of *C. Wrightii*, but it is less flattened at the extremities. In some cases, as in those figured, the tubercles are particularly well-marked; in the

var. *baccata*, which may be a distinct species, they are broader (quite half the breadth of the spiral cell) and almost contiguous. We found one fruit in the Mammal-Bed closely resembling that of *C. cœlata*, but having holes at regular intervals in place of tubercles (Pl. VI, fig. 9).

Obtained from the Limestone-Band, and one specimen of *C. cœlata* var. *baccata* from the Basement (Seed)-Bed.

3. Chara vasiformis, sp. nov. (Pl. IV, figs. 12–15.)

Oogonium obovoideum deorsum ad basem insignem pentagonum plerumque fastigatum, magnitudine variata, long. c. 750–950 μ, crass. c. 475–725 μ; cellulæ spirales lat. c. 75–100 μ, crass. c. 50–60 μ, apice paulo dilato, cum ordine tuberculorum eminentium truncatorum, convolutiones decem–duodecim exhibentes; foramen basilare plerumque latum infundibuliforme. [Oospora obovoidea, long. c. 650–725 μ, crass. c. 450–500 μ, liras eminentes c. novem exhibens: cohors basilaris diametro c. 125 μ.]

A well-marked fruit very variable in size, usually pale brown. Evidently allied to *C. tuberculata* Lyell, from the Bembridge Beds, but differing in its smaller size, in being more or less obovoid, rather than ellipsoid, and in having usually a more prominent vase-like base, which latter feature does not come out well in our figures. The tubercles of the other tuberculate-fruited species are either rounded or conical, whereas in *C. tuberculata* and *C. vasiformis*, when fully developed, they are abruptly truncated, the apex being flat. The probable explanation of this is that the extent of their development was limited by the cell wall. In a very small proportion of the fruits the tubercles are absent (see fig. 14). In some there are smaller irregular intermediate tubercles forming a serrated ridge along the centre of each spiral cell. We were in doubt as to the origin of the tubercles: that is, whether they were possibly merely a calcareous encrustation, or were organic. Our friend, Mr. D. J. Scourfield, a skilled microscopist and biologist, kindly made a careful examination of them, and reported as follows:—

'The tubercles are very peculiar, but I have come to the conclusion that they are actual productions of the plant. If a piece of a spiral be examined, it will be seen that, despite much irregularity of growth along the whole course of the spiral, the more or less flat-topped projections (that is, the tubercles properly so called) are spaced at fairly constant intervals. The amount of these growths varies from nothing on some specimens to an almost continuous band on others. I suppose that this depends on the stage of development of the fruit. If a piece of one of the spirals be treated with weak acid the carbonate of lime will be seen to be gradually dissolved away, leaving an exact copy in some organic substance (? cellulose) with a rather wrinkled surface. A number of very minute crystals (? substance) are embedded in this, and also usually a number of somewhat rounded grains, probably sand-grains, as they do not dissolve in fairly strong nitric acid.'

From the Limestone-Band a few fruits were obtained, of which the apex was prolonged into a point. (See Pl. IV, fig. 15.)

In the gathering from the Basement (Seed)-Bed, in addition to a number of loose oospores, some were obtained in their enclosing oogonia, and it is upon these that the description of the oospore is based; but the measurements, etc. may not apply to those of the other beds. The uniformly salient vase-like base separates this and *Chara tuberculata* from all the other species.

Obtained from the Mammal- and Basement (Seed)-Beds, the Limestone-Band, the Rodent-Bed, and the Mineway. Next to *C. Wrightii* this is the most frequent species.

4. CHARA DISTORTA, sp. nov. (Pl. V, fig. 6.)

Oogonium ellipsoideo-fusiforme, long. c. 1000–1200 μ, crass. c. 875–925 μ; cellulæ spirales latissimæ (c. 150 μ) et crassissimæ (c. 150 μ) plerumque convexæ, apice haud multo dilato, convolutiones irregulares septem–octo exhibentes; foramen basilare angustum, ore paulo dilato.

Of a dark purplish-brown, varying much in size and shape, but characterized by the usually somewhat tapered apex and base, and by the irregularly-coiled spiral cells. It is not unlike an extended form of *C. Wrightii*. So far as can be gathered from A. Watelet's description and somewhat crude illustrations of his *C. depressa*,[1] *C. distorta* resembles that species, but differs from it in the form of the apex of the spiral cells.

Obtained in fair quantity from the Rodent-Bed.

5. CHARA HELICTERES, Brongniart, in G. Cuvier & A. Brongniart's 'Description Géologique des Environs de Paris' 1822, p. 368 & pl. xi, fig. 8. (Pl. V, fig. 11.)

Oogonium late ellipsoideum, apice plus minusve truncatum, long. c. 1050–1200 μ, crass. 950–1050 μ; cellulæ spirales convexæ, in apice turgidæ et plerumque ad jugum constrictæ, convolutiones regulares octo–novem exhibentes; foramen basilare latum et haud profundum, margine cum angulis acutis et plerumque prætendentibus.

The fruits are variable in shape, usually decidedly longer than broad, but sometimes almost spherical, often conspicuously flattened at the apex and occasionally tapering somewhat towards the base. The Hordle specimens are of a light brown with a smooth surface. The dimensions are smaller than those given by Schimper in his 'Traité de Paléontologie Végétale' vol. i (1869) p. 222 & pl. v, figs. 20–32. That author shows the number of convolutions of spiral cells displayed as eleven; but in Brongniart's original figure eight only are shown.

Obtained from the Mammal-Bed and Mineway.

[1] 'Description des Plantes Fossiles du Bassin de Paris' 1866, p. 55 & pl. xv.

6. Chara tornata, sp. nov. (Pl. V, figs. 1–3.)

Oogonium ellipsoideum vel cylindrico-ellipsoideum, long. c. 550–700 μ, crass. 400–475 μ, apice paulo acuto, base truncato; cellulæ spirales convexæ, lat. et crass. c. 65 μ, ad apicem dilatæ sed complanatæ, ad basem dilatæ, convolutiones c. duodecim exhibentes; foramen basilare paulo latum et haud profundum, margine cum angulis deorsum prætendentibus. Oospora ellipsoidea apice truncato, long. c. 600–700 μ, crass. c. 350–400 μ, liras subhumiles novem–decem exhibens; cohors basilaris diametro c. 100 μ.

A distinct well-marked type, pale yellowish to dark brown. The regular rounded spiral cells give it a particularly neat appearance; the flattened (collapsed) apices cause the fruit to seem pointed at the apex, while the five obtuse points of the basal aperture, projecting downwards, produce a truncated outline below.

Plentiful in the Mammal- and Basement (Seed)-Beds, and occurring also in the Rodent-Bed. In the Basement-Bed oospores are present.

7. Chara subcylindrica, sp. nov. (Pl. V, fig. 4.)

Oogonium ellipsoideo-cylindricum, long. 475–600 μ, crass. 275–350μ; cellulæ spirales convexæ, lat. c. 65μ, ad apicem paulo dilatæ, convolutiones c. duodecim exhibentes; foramen basilare latum et haud profundum, margine cum angulis deorsum prætendentibus.

Resembling the species last described, but smaller and proportionally narrower and more rounded at the extremities. A few whole specimens only were found, and these differ considerably in size. Four broken specimens, with but slightly developed lime-shell and consequently concave spiral cells, obtained from the Rodent-Bed (fig. 5), probably also belong to this species.

Mammal- and Basement (Seed)-Beds, and (?) Rodent-Bed.

8. Chara polita, sp. nov. (Pl. V, figs. 9 & 12.)

Oogonium globoso-ellipsoideum, ad basem paulo fastigatum, long. 675–750 μ, crass. 625–675 μ; cellulæ spirales leves lat. c. 80–100 μ, ad apicem paulo dilatæ, convolutiones octo–decem exhibentes; foramen basilare diametro c. 65 μ, ore paulo dilato.

Brown to nearly black, when fully developed smooth and shining, varying somewhat in form, but usually having the base and apex rounded. A few rather larger fruits, with the spiral cells showing one or two more convolutions, may belong to this species.

Limestone-Band, fairly numerous.

9. Chara strobilocarpa, sp. nov. (Pl. V, figs. 7 & 8.)

Oogonium obovoideum deorsum conspicue fastigatum, apice rotundato, long. 850–1000 μ, crass. 550–600 μ; cellulæ spirales concavæ, lat. c. 100–125 μ, ad apicem et basem dilatæ, convolutiones novem–undecim exhibentes; foramen basilare parvum, valde angulatum.

Var. ELLIPSOIDEA. Oogonium ellipsoideum, sursum et deorsum paulo fastigatum. (Pl. V, fig. 10.)

Var. BITRUNCATA. Oogonium bitruncato-ellipsoideum, nonnunquam ad basem paulo fastigatum; foramen basilare diametro medio. (Pl. V, fig. 13.)

The type varies in size and shape, the specimen figured being the largest and most distinctive. The variety *ellipsoidea* differs from it in being somewhat tapered at both ends, slightly more below than above; the variety *bitruncata*, on the other hand, has usually both ends somewhat truncate.

The type and the variety *ellipsoidea* were obtained from the Limestone-Band, only two specimens of the latter being found; the variety *bitruncata* was obtained in fair quantity from the Rodent-Bed, and a single specimen from the Basement (Seed)-Bed.

10. CHARA TURBINATA, sp. nov. (Pl. VI, fig. 1.)

Oogonium obovoideum, apice insigne complanato, ad basem truncatam fastigatum, long. c. 625–650 μ, crass. c. 400–450 μ, cellulæ spirales lat. c. 65 μ, plerumque complanatæ ad apicem et basem dilatæ, convolutiones novem–decem exhibentes; foramen basilare latum, margine angulis prætendentibus.

A distinct-looking type, pale yellowish-brown, usually tapering decidedly towards the base.

Limestone-Band, a few specimens only.

11. TOLYPELLA HEADONENSIS, sp. nov. (Pl. VI, figs. 2 & 3.)

Oogonium subglobosum ad basem levissime fastigatum, long. c. 450–475 μ, crass. 400–425 μ; cellulæ spirales lat. c. 60 μ, crass. c. 40 μ, ad apicem turgidæ, convolutiones novem–decem exhibentes; foramen basilare parvulum, margine prominente.

Fruits buff-coloured, with regular spiral cells, somewhat resembling in shape those of the living species *T. prolifera*, but more globose, and having the tips of the spiral cells swollen, implying a deciduous coronula. The concavity of the spiral cells in this and the following species corresponds with what is usually seen in the dried fruits of the two living British species which secrete a lime-shell.

Obtained in fair quantity from the Rodent-Bed.

12. TOLYPELLA PARVULA, sp. nov. (Pl. VI, figs. 4 & 5.)

Oogonium globoso-obovoideum ad basem subacutam paulo fastigatum, long. c. 325–375 μ, crass. c. 225–275 μ; cellulæ spirales concavæ, lat. c. 40 μ, crass. c. 30 μ, ad apicem haud aut leviter dilatæ, convolutiones novem–undecim exhibentes; foramen basilare parvulum, margine prominente.

Fruits cream- or buff-coloured, differing in size and shape from

the foregoing and in having probably had a persistent coronula. They are smaller than those of any living *Tolypella*.

Obtained in fair quantity from the Limestone-Band.

Vegetative Remains. (Pl. VI.)

A large proportion of the remains of stems and branchlets appear to belong to a single type, designated as A (Pl. VI, figs. 10–12), of which the following are the characteristics:—

STEMS.—The remains of these consist of numerous short fragments. The diameter ranges from c. 250 μ to c. 400 μ, and the rows of cortical cells from about fourteen to twenty. The latter are usually of like diameter and always contiguous. There is usually considerable torsion visible in the cortex, and this is invariably dextral, as in the living Chareæ. The arrangement of the cortical system is difficult to elucidate, on account of the fragmentary character of the remains; but, from the number of rows, it may perhaps be presumed to be diplostichous, that is, having one row of secondary cortical cells to each primary row. This cannot, however, be determined, as there is no marked difference in the diameter or prominence of the rows, and no node-cells have been made out, to indicate the primary series. The cortical cells are evidently long; but their length has not been determined, as in no case has an entire cell been found. Portions have, however, been observed, measuring as much as 1250 μ. The ends of the cortical cells seem usually to taper considerably, often to a sharp point; but, whether these belong to a secondary series, or are the terminal cells of the primary series, is not apparent.

BRANCHLETS.—The remains of these are fairly numerous, but are also extremely fragmentary. They vary in thickness from about 170 to 250 μ. Like those of living species, they show little torsion. The cortex is regular, the number of cells being about fourteen to sixteen, so that the arrangement in this case may be presumed to be diplostichous, as in nearly all living species; but no trace of bract-cells has been found. Nodes are frequent, and are indicated by a unilateral swelling of the branchlet at the spot, and by the meeting of the bases of the ascending and descending cells in a more or less even circle. The length of the cortical cells of the branchlets also cannot be determined, as in no case has a complete cell been found; but that the length is evidently very irregular is indicated by the fact that the points of meeting of the apices of the ascending and descending cells do not coincide in adjoining rows.

The cortical cells of both stems and branchlets are found in a collapsed condition, presumably from desiccation, resembling those of dried specimens of recent species, and therefore appear as grooves instead of cylinders.

From the diameter of the stems and branchlets this type may be presumed to belong to a plant of about the stature of *Chara fragifera*.

The rest of the vegetative remains found, irrespective of the nodes, which will be dealt with separately, appear to belong to four types, as follows:—

TYPE B.—Short fragment of a small stem, shown in section in Pl. VI, fig. 13, about 375 μ in diameter (including cortex), with eight markedly non-contiguous cortical cells, the cortex being evidently haplostichous in character, that is, having primary series only developed, so that the number of rows of cortical cells equals that of the branchlets. The cells are not collapsed.

TYPE C (Pl. VI, fig. 14).—Several short portions of a medium-sized stem about 500 μ in diameter, with eight to ten cortical rows, usually non-contiguous, and for this reason, as also from the number of rows, presumably haplostichous.

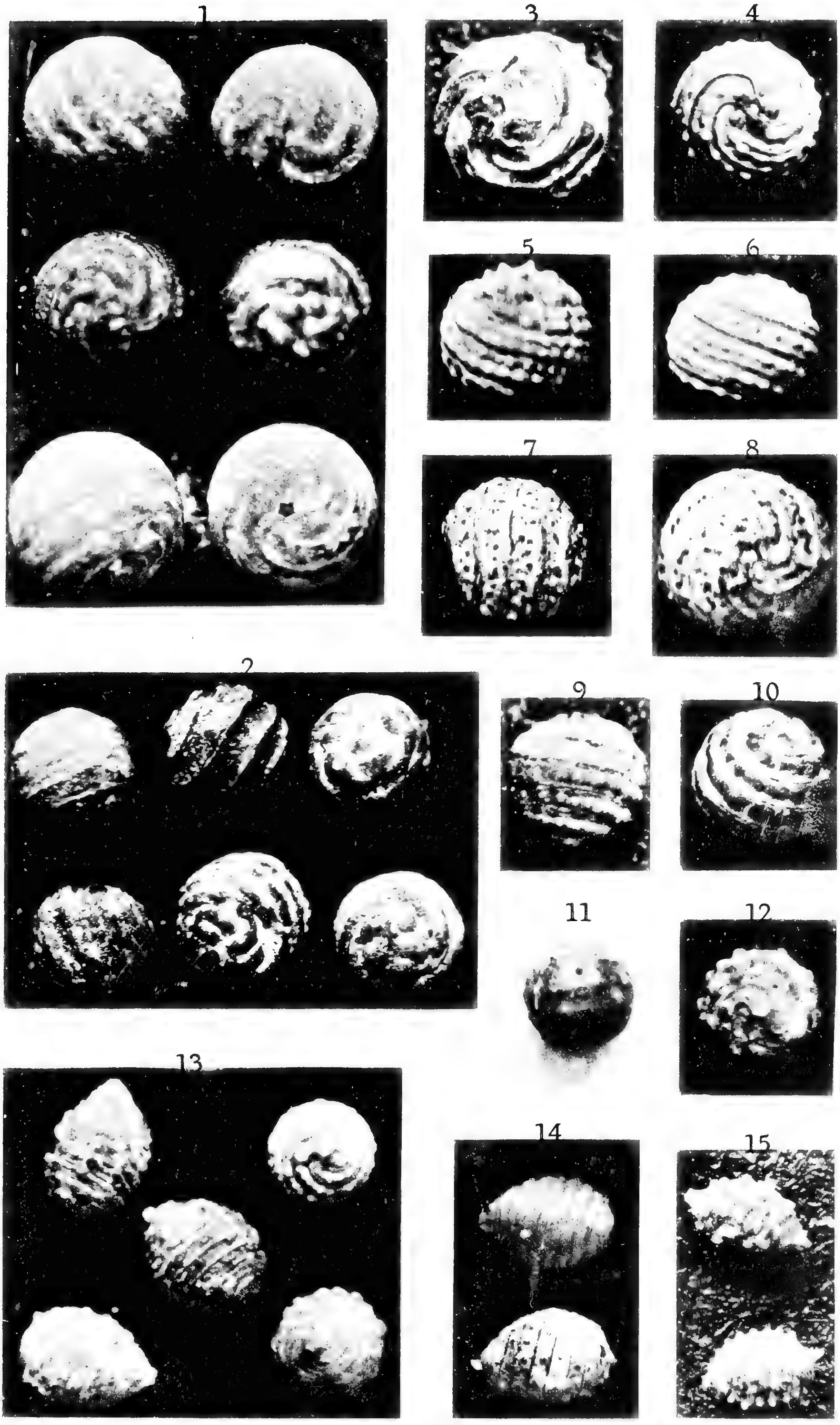
TYPE D (Pl. VI, figs. 15 & 16).—A few small fragments of a large type of stem, which can only be conjectured to be about 1300 μ in diameter, no complete cylindrical portion having been found. The cortical cells are very large (about 160 μ in diameter), firm and thick-walled, and their number would probably be about 12. The cortex would appear to be irregular from the portions shown in fig. 15, and the cells are nodulose. There is no evidence as to whether the cortex is haplostichous or diplostichous; but perhaps the number of rows may be regarded as suggesting that it belongs to the former category. The diameter of the stem, if correctly estimated, would suggest a plant of about the stature of *Chara rudis*.

TYPE E (Pl. VI, figs. 17 & 18).—A few portions of small to medium-sized, hollow, cylindrical bodies, belonging presumably to an ecorticate Characeous plant, with small elongated bodies, resembling the spine-cells of recent species, attached and projecting at about a right angle. The nature of these latter has not been made out, and it is probable that they are foreign bodies. As they do not proceed from nodes, they cannot well be spine-cells, and as they do not communicate by a pore at the base with the internodal cell on which they occur, they evidently are not akin to the rosette-cells of *Clavator*. We hope that the discovery of more specimens of this type may result in an elucidation of its peculiarities.

The bodies shown in Pl. VI, fig. 19 are probably stem-nodes from which the branchlets have been separated. If this be the case, the number of branchlets, as indicated by the scars, would be nine to eleven. Fig. 20 shows what is apparently a less complete node of a much larger species, perhaps Type D.

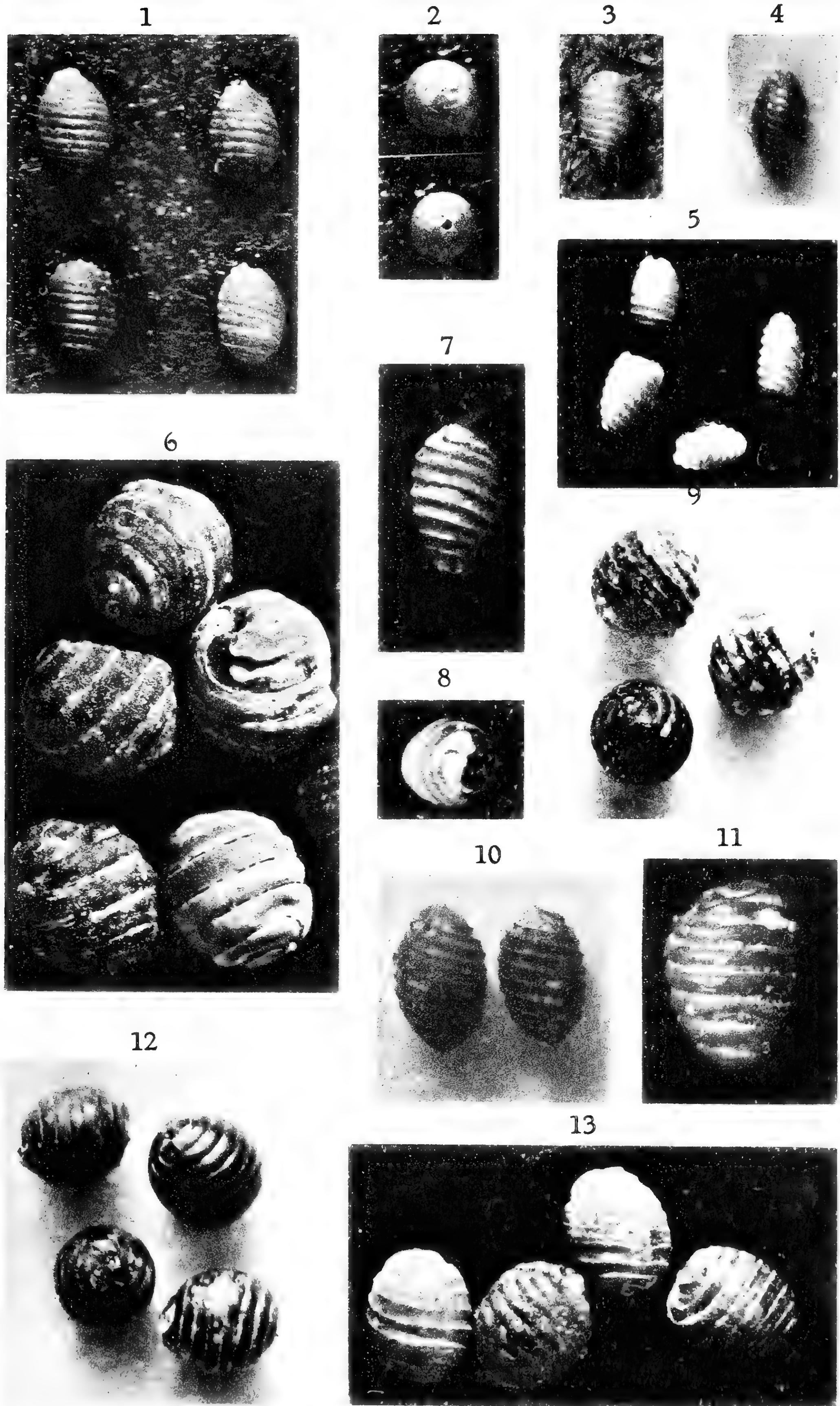
The specimens already mentioned were all obtained from the Limestone-Band.

The stem-node with bases of branchlets attached (Pl. VI, fig. 21), obtained from the Rodent-Bed, belongs apparently to an ecorticate plant. The interior diameter of the stem is about 300 μ, the



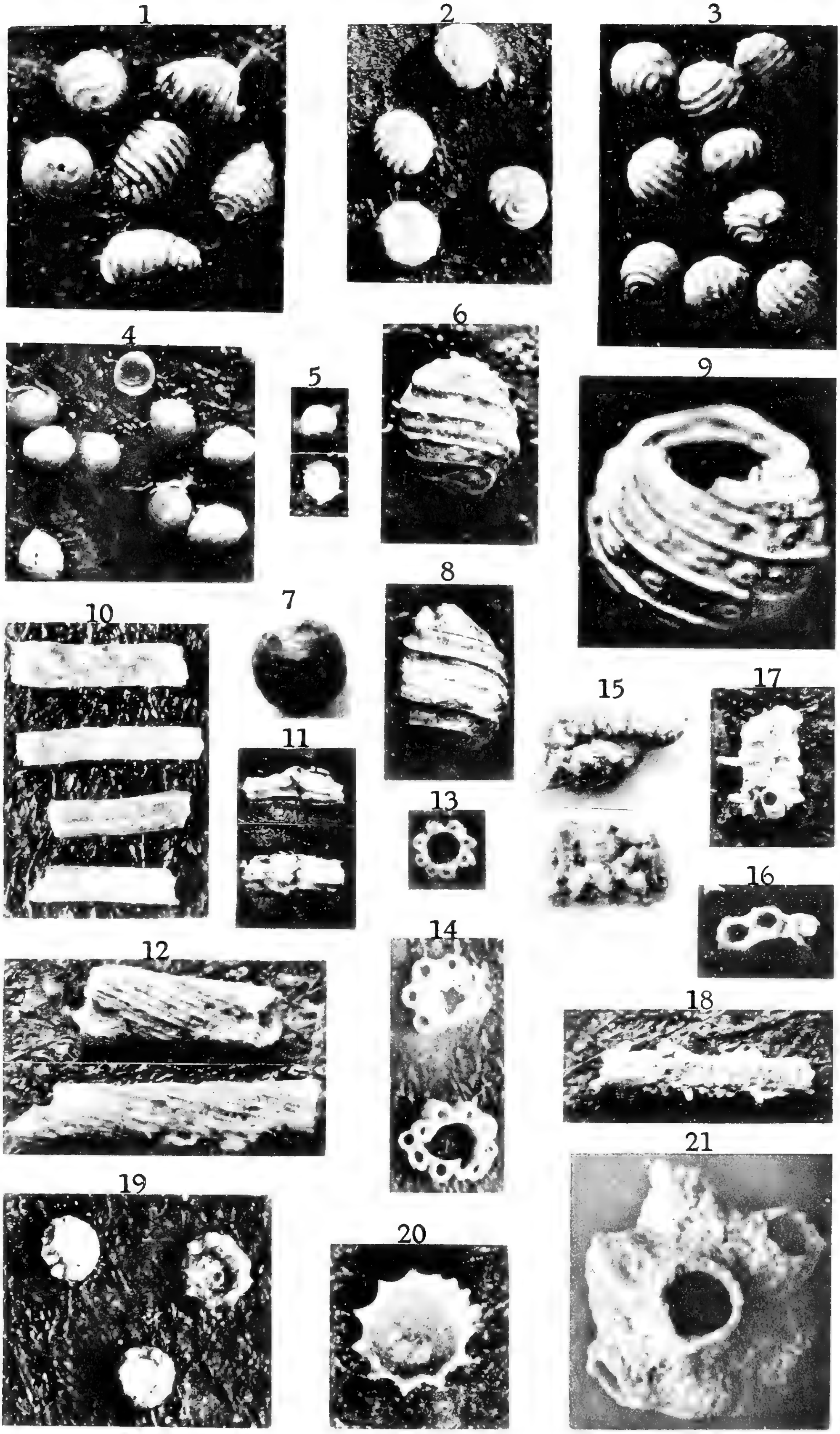
C.R. photo.

CHAROPHYTA FROM THE LOWER HEADON BEDS



C.R. photo.

CHARAPHYTA FROM THE LOWES HEADON BEDS



C.R. photo.

CHAROPHYTA FROM THE LOWER HEADON BEDS

exterior about 450 μ. The apparent thickness of the cell-wall is evidently in part due to encrustation. The branchlets are six in number, and the internal diameter is about 250 μ.

The small number of the branchlets and the apparently ecorticate stem suggest the possibility that it belongs to one of the *Nitelleæ*, perhaps *Tolypella headonensis*, the fruits of which come from the same bed.

Some remains, collected by Mr. Reid from the Basement (Seed)-Bed, had not been examined during his lifetime. This gathering has proved particularly valuable, as in addition to the entire oospores present *in situ*, referred to under species 1, 3, & 6, it includes a fair quantity of the vegetative parts, among which there are several more or less complete stem-nodes with small portions of the internodes and branchlets attached. This vegetative material is unfortunately very much encrusted and extremely friable, so that it is almost impossible to make out some of the details of structure. The portions of detached stem, some of which are well preserved, all apparently belong to one of two types. Of Type 1 the internodal cell ranges from about 375 to 500 μ in diameter, and has a haplostichous cortex formed of ten contiguous or almost contiguous rows of large cells measuring about 100 to 125 μ in diameter. The cortical cells are frequently nodulose, and on some of them there are apparently clusters of three or four spine-cells. The stem therefore resembles among living species the uncommon but widely distributed *Chara canescens*. An imperfect node showing corticate branchlets probably belongs to the same species; but there is no portion of the stem-internode attached.

Type 2 has the internodal cell of about the same diameter, with a haplostichous cortex formed of about ten distinctly non-contiguous rows of small cells of less than half the diameter of those of Type 1. Most of the stem-nodes appear to belong to this type, and the branchlets apparently are uniformly ecorticate and about ten in number. There are traces of fairly large stipulodes on some of the nodes, but the encrustation prevents them from being clearly seen. In one instance there are sections of a large number of outstanding cells at the base of the branchlets. In others there appears to be only one stipulode to each branchlet. The stem-cortex of this type resembles among living species that of the rare Western European and North African *Chara imperfecta*, but that species has rudimentary stipulodes.

EXPLANATION OF PLATES IV–VI.

[All the figures are magnified 20 diameters, except figs. 9 & 21 in Pl. VI.]

Plate IV.

Fig. 1. *Chara Wrightii*. (See p. 183.)
2. *C. Wrightii*, var. *minor* nov.
3. *C. Wrightii*, var. *rhytidocarpa* nov.
Figs. 4–6. *Chara cælata*, sp. nov. (See p. 184.)

Figs. 7 & 8. *Chara cælata*, var. *bicincta* nov. (See p. 184.)
9 & 10. *C. cælata*, var. *baccata* nov.
Fig. 11. Oospore of *Chara Wrightii (?)*. (See p. 184.)
Figs. 12–15. *Chara vasiformis*, sp. nov. (See p. 185.)

PLATE V.

Figs. 1–3. *Chara tornata*, sp. nov. (See p. 187.)
Fig. 4. *Chara subcylindrica*, sp. nov. (See p. 187.)
5. *C. subcylindrica (?)*.
6. *Chara distorta*, sp. nov. (See p. 186.)
Figs. 7 & 8. *Chara strobilocarpa*, sp. nov. (See p. 187.)
Fig. 9. *Chara polita*, sp. nov. (See p. 187.)
10. *Chara strobilocarpa*, var. *ellipsoidea* nov. (See p. 188.)
11. *Chara helicteres* Brongniart. (See p. 186.)
12. *Chara polita*, sp. nov. (See p. 187.)
13. *Chara strobilocarpa*, var. *bitruncata* nov. (See p. 188.)

PLATE VI.

Fig. 1. *Chara turbinata*, sp. nov. (See p. 188.)
Figs. 2 & 3. *Tolypella headonensis*, sp. nov. (See p. 188.)
Fig. 4. *Tolypella parvula*, sp. nov. (See p. 188.)
5. *T. parvula (?)*.
Figs. 6–8. *Chara* spp. (?).
Fig. 9. Perforated oogonium of *Chara cælata (?)* ×40.
Figs. 10 & 11. Portions of branchlets, Type A. (See p. 189.)
Fig. 12. Portions of stem, Type A.
13. Section of stem, Type B. (See p. 190.)
14. Section of stem, Type C. (See p. 190.)
Figs. 15 & 16. Portions of cortex, Type D. (See p. 190.)
17 & 18. Portions of stem, Type E. (See p. 190.)
19 & 20. Stem-nodes (?). (See p. 190.)
Fig. 21. Stem-node, with portions of stem-internode, and bases of branchlets. ×27.

DISCUSSION.

Dr. M. C. STOPES congratulated the Authors warmly upon their work, which seemed to be the kind of palæobotanical work much to be desired at present. She remarked on the exceptional nature of the Characeæ in depending so greatly on huge single cells for their external and visible morphological features, and suggested that the dearth of *Chara*-remains in the blackened and carbonaceous layers might be due to the solution of their native carbonates prior to fossilization in water with excess of carbon dioxide. She asked whether in the well-preserved fruits the carbonates were replaced by silicates to any extent, and whether the new bossed and ornamented forms of fruits could be compared at all with the skeletal or shell enlargements of certain races of animals arising some time before extinction.

Mr. J. GROVES expressed his regret at the unavoidable absence of Mr. Clement Reid. He thanked Dr. Stopes for her remarks, and in reply to her questions, he stated that he did not find any appreciable trace of silicates in the fossil fruits, which dissolved almost entirely when treated with acid; he also stated his opinion that the pronounced ornamentation of the Characeæ could not be regarded as a phase of development that preceded extinction. He thanked the Fellows for their reception of the paper.

9. *On* SACCAMMINA CARTERI BRADY, *and the* MINUTE STRUCTURE *of the* FORAMINIFERAL SHELL. By Prof. WILLIAM JOHNSON SOLLAS, Sc.D., LL.D., F.R.S., F.G.S. (Read February 23rd, 1921.)

[PLATE VII.]

THIS remarkable foraminifer, which contributes so largely to the formation of some of our Carboniferous Limestone beds, was first described by H. B. Brady in 1871,[1] and assigned by him to the existing arenaceous genus *Saccammina* (Sars [2]). His views on its structure and taxonomic affinities have been accepted without question by all subsequent writers, and are embodied in our textbooks on palæontology. Brady himself, however, was evidently puzzled by certain features presented by the structure of the shell: thus, in his latest description,[3] after stating that the shell is compact and arenaceous with a nearly smooth exterior, he remarks (p. 60) of the interior surface that it

> 'varies a good deal in different specimens,' sometimes being 'smooth or roughened only by the projecting angles of the constituent sand-grains [and at others] covered with a network of short delicate labyrinthic growths.'

Of the minute structure of the shell he finds it

> 'difficult to speak in positive terms, owing to peculiar conditions of infiltration.'

Finally, he calls attention to certain

> 'minute circular scars, too frequent and uniform not to have a meaning, [and suggests] ... that they may result from the repair of an injury to the test.'

As a specimen of the *Saccammina* Limestone, from the classic locality of Elfhills in Northumberland, crowded with remains of this organism, forms part of the teaching collection in the University of Oxford, it devolved upon me to make myself familiar with its structure. My examination led me to recognize the fidelity of Brady's description, and at the same time to find an explanation for what had seemed anomalous. Whether the fossil is to be classed with arenaceous forms or not is a difficult question, which will be considered later.

Weathered specimens, on which Brady's description seems chiefly to have been based, show the labyrinthine structure to which he refers very clearly, and as well the circular 'scars' on the exterior. The latter may be recognized at a glance as the familiar 'beekite,' that form of chalcedony which, owing to its mode of growth, and

[1] H. B. Brady, 'On *Saccammina Carteri*' Ann. & Mag. Nat. Hist. ser. 4, vol. vii (1871) p. 177.

[2] S. Sars, 'Fortsatte Bemærkninger over det Dyriske Livs Udbredning i Havets Dybder' Vidensk. Selsk. Forh. 1868, p. 248; 1871, p. 250.

[3] H. B. Brady, 'Carboniferous & Permian Foraminifera' Palæont. Soc. Monogr. 1876, pp. 56–61.

perhaps colloidal origin, assumes the rounded contours of organic form that have proved misleading to more than one distinguished observer. In this case it is responsible, both for the 'scars' and, as we shall see directly, for the labyrinthine structure.

The isolated chambers of the fossil, rarely connected together, are thickly scattered through the limestone, so that if the minerals now filling their interior were removed the rock would be rendered highly vesicular, in some cases as much as from a third to a half of its volume would then be occupied by empty space.

An examination of thin slices under the microscope reveals considerable diversity in the mineral changes which have followed on the death of the animal.

In the best-preserved examples the wall of the chamber is a very thin calcareous shell of uniform thickness, presenting a smooth surface both within and without. It consists of an irregular mosaic of minute calcite-crystals, which by its comparative purity and transparency, in striking contrast with the dark dusty appearance of the surrounding matrix, is well defined on the exterior. On the interior also it is well defined, partly by washed-in matrix—which in rare examples completely fills the test, but is more usually present only in patches—, partly by a growth of very minute calcite-crystals, which are often more nearly colourless than the wall, but appear darker in mass owing to their more abundant interspaces and in consequence the greater loss of light by internal reflection. In some cases a thin layer of black carbonaceous granules with associated granules of iron pyrites lies next the inner surface, and marks it off in bolder outline (Pl. VII, figs. 10, 13). L. Rhumbler[1] has called attention to the presence of granules of pyrites in the chambers of the recent species of *Saccammina* (*S. sphærica*) as well as of several species of perforate forms, and remarks that it may sometimes be seen in the decomposing sarcode still present in the chambers of dead foraminifera. He explains its formation as due to the reduction of ferrous sulphate by organic matter. This view is in harmony with the intimate association of carbonaceous matter and pyrites in our specimens.

Owing to the excellent definition of the boundary of the chamber-wall on both sides, its thickness may be measured with considerable accuracy. This amounts in the great majority of cases to 0·05 mm.; but it may be less, sometimes falling to 0·02 mm.: or it may be more, as much occasionally as 0·08 mm.

Passing now to the mineral infilling of the chamber, we find that in the simplest case its cavity is completely occupied by a coarse mosaic of calcite which has grown from the wall inwards. Some of the crystals of the fine mosaic which forms the wall have shared in this secondary growth, and project inwards a little beyond the inner boundary, which thus assumes an appearance

[1] 'Beiträge zur Kentniss der Rhizopoden, II.' Zeitschr. f. Wissensch. Zool. vol. lvii (1894) pp. 433–617, in particular p. 571.

that has been mistakenly supposed to indicate an arenaceous structure. That this is a secondary character which did not exist during life, but was subsequently acquired, is shown in some cases by the presence of a thin dark line which sharply separates the later growth from the original mosaic of the test: but, even without this evidence, the mode of growth of the secondary crystals sufficiently reveals its true nature.

In the next case quartz contributes to the infilling of the chamber (Pl. VII, figs. 9, 12). The mosaic of calcite extending inwards from the wall may fail to reach the centre, leaving a larger or smaller space which is then filled with quartz, sometimes, as seen in sections, by a single crystal, sometimes by a mosaic.

Usually, when quartz is present, it is accompanied by chalcedony (Pl. VII, figs. 8, 14) which first attacks the wall of the chamber, often completely replacing the mosaic of calcite, and then extends for a greater or less distance inwards. Where it invades the wall, its fibres start from centres on the inner boundary and radiate outwards; where it fills the interior, its fibres also originate in centres on the inner boundary, but radiate inwards. This inward growth evidently proceeded rhythmically, zones of chalcedony alternating with zones of quartz, in the fashion so familiar to us in agate: in some instances as many as seven of these zones may be counted in a deposit 0·6 mm. thick.

The chalcedony may be readily distinguished from the quartz in ordinary light, partly by its faint yellowish-brown tint (the quartz being absolutely colourless), and partly by its finely granular appearance and less perfect transparency. But it requires polarized light to reveal the minute structure of the chalcedony in all its beauty.

In some cases the outer third of a chamber may be filled with chalcedony, the middle third with calcite, and the central region with quartz: or the outer zone may be formed by an interpenetrating growth of chalcedony and calcite, and then we have the labyrinthine structure described by Brady.[1]

In the light of this explanation it is interesting to read Rhumbler's[2] account of a labyrinthine structure in the wall of a living species (*Nodosinella gausica*), which he regards as comparable with that of *Saccammina carteri*.

In concluding this description I may call attention to the abundant presence in the *Saccammina* Limestone of thin bands of calcite mosaic, curved in circular arcs, which by their structure, thickness, and radius of curvature may be recognized as fragments of the chamber-wall. Thus the organism has contributed far more to the substance of the limestone than would be concluded from observation of the unbroken chambers alone.

[1] H. B. Brady, *op. cit.*, see in particular pl. i, figs. 5 & 6.

[2] L. Rhumbler, 'Die Foraminiferen der Plankton-Expedition' Ergebnisse der Plankton-Expedition der Humboldt-Stiftung, vol. iii, pt. 2 (1913) p. 452.

We have now to consider the systematic position of the fossil. The complete mineralization which it has undergone seemed to render it doubtful whether the existing structure of the wall could be considered original, or whether it might not be due to a *post-mortem* molecular rearrangement; and this led me to doubt whether it was ever arenaceous, and consequently whether it had any claim to a close alliance with *Saccammina sphærica*, such as is generally assumed.

It became necessary, therefore, to search in the first place for some criterion by which the perforate and imperforate foraminifera might be distinguished one from the other when occurring in the fossil state. I was thus led to investigate the minute structure of their shell, and succeeded in obtaining some results, which, though by no means exhaustive, seem to be of sufficient interest to be introduced here. As a preliminary, I ought to remark at once that there is no difference in the mineral composition of the two kinds of shell: it consists both in Perforata and Imperforata of calcite. The statement, for which I am responsible, that the shell of the Imperforata consists of aragonite is erroneous; it was based on determinations of specific gravity, which, though correct in themselves, were made on specimens containing foreign matter, the presence of which was not suspected at the time.

Dr. J. J. Lister was the first to establish the true nature of the mineral present in the Imperforate shell; he found that the shells of both Perforata and Imperforata give the well-known calcite reaction with cobalt nitrate. I have repeated his experiments with the same result, and have obtained further confirmation by treatment with ammonium ferrous sulphate. As these tests, however, are not always decisive,[1] renewed observations were made on the specific gravity of the shells both of the Perforata and Imperforata, using for the former some *Globigerina* ooze, rich in *Orbulina*, which was dredged by the 'Challenger' from 1990 fathoms in lat. 20° 17′ S., long. 14° 2′ W. This was freed from fine powder by washing in water, dried, and placed in a diffusion-column. The *Globigerina* and *Orbulina* gave results of no value, owing to the presence of impurity, probably argillaceous matter; but on the *Orbulinæ* being crushed swarms of young *Globigerina* were set free; they were clear, colourless, and transparent, and floated in a zone of specific gravity ranging from 2·714 to 2·706.

For the Imperforata, *Orbitolites* from the sands of Funafuti were selected. After being dried at 100° C. they were ground to a fairly fine powder in an agate mortar, and placed in a diffusion-column where they formed a dense zone of mean specific gravity 2·724; but many fine particles and some coarser fragments extended upwards to 2·65, and a smaller quantity downwards to 2·86 or more.

If we take the specific gravity of the zone as a basis, and assume the presence of organic matter to the extent of 1·4 per cent., as in

[1] J. Johnston, H. E. Merwin, & E. D. Williamson, 'The Several Forms of Calcium Carbonate' Amer. Journ. Sci. ser. 4, vol. xli (1916) p. 478.

conchite, with a specific gravity of 1·4 we may calculate the specific gravity of the purely mineral ingredient. It comes to 2·742. But the published analysis of *Orbitolites* shows that 98·27 per cent. of this ingredient consists of 9·55 per cent. of magnesium carbonate and 88·72 per cent. of calcium carbonate, and thus its specific gravity should be 2·742. That this number should be identical with the preceding is an accident, since no account has been taken of the traces of alumina and iron peroxide present in the shells; but the agreement is sufficiently in harmony with Dr. Lister's conclusion founded on a chemical method.

A more fundamental difference between the Perforate and the Imperforate shell is provided by the minute structure of its wall.

It is well known that the wall in simple forms of the Perforata is found, when examined between crossed nicols under the microscope, to consist of rods of calcite arranged with their principal axes directed parallel to the pore-canals: that is, with their optic axis normal to the surface, so that a spherical chamber, such as occurs in *Orbulina* or *Globigerina*, may be regarded as built up of prisms, each with its optic axis corresponding to a radius of the sphere. Hence, between crossed nicols, it presents a dark, well-defined cross which remains stationary on rotation of the stage of the microscope.[1] A petrologist might regard it as a hollow spherulite. That the optic axes lie normal to the surface is shown by the optical sign which, as S. Awerinzew[2] was the first to show, is negative.

In the most complicated forms of the Perforata, such as Nummulites, the fundamental skeleton is constituted according to the same law, and this is true also of *Calcarina* and *Tinoporus*, but I am unable to speak in detail of the supplemental skeleton, which requires further examination.

The Perforate structure generally survives the changes which accompany fossilization, and it frequently but not always determines the crystallographic orientation of the calcite which is deposited within and around the test after death.[3] Simple forms then present the dark cross as plainly after fossilization as before.

[1] It may be observed in passing that coccoliths (Discoliths and Cyatholiths) when examined in this way also give a dark cross; the arms of the cross are, however, not always straight, but frequently curved in a manner suggestive of a slightly spiral arrangement. The illuminated segments between the arms contrast by their brilliance with the dark field of the microscope. Advantage may be taken of this fact when one is searching for coccoliths dispersed through fine sediment.

[2] 'Ueber die Struktur der Kalkschalen Mariner Rhizopoden' Zeitschr. f. Wissensch. Zool. vol. lxxiv (1903) p. 478.

[3] It is not only among the Perforate Foraminifera that the molecular structure of the skeleton persists throughout fossilization, and dominates that of any subsequently-deposited calcite. The spicules of a calcareous sponge (which are composed of calcite), when placed in a solution of dihydric calcium carbonate, become covered with a growth of calcite which crystallographically is merely an extension of the original spicule. The ossicles of Echinoids furnish a more familiar example.

The striking difference in the outward appearance of the Perforate and the Imperforate shell is due to an equally striking difference in their minute structure.

The structure of the Imperforate shell is, however, by no means what is generally supposed. As seen by ordinary light under the microscope a thin section of such a form as *Orbitolites*, for instance, presents much the same appearance as chitin, and it was quite natural that the earlier observers should have concluded that the shell consists of a basis of this substance impregnated with carbonate of lime.

On decalcification with dilute acid an organic residue is obtained which retains the form of the shell. It consists most obviously of a delicate membrane or cuticle, which lines the walls of the chambers and invests the interior of the shell. In ordinary circumstances nothing more is visible; but, with appropriate treatment—staining with methylene blue—a delicate network is revealed, which extends through the substance of the shell from the lining membrane on one side to that on the other. This was first shown by F. Schaudinn [1] in his study of *Calcituba*, and subsequently by S. Awerinzew [2] in *Peneroplis* and *Miliolina*. Confirmatory observations were afterwards made by F. W. Winter.[3] Stress has been laid by those authors on the facility with which this network may escape observation. This accords with my own experience. Some specimens of *Orbitolites* from Fiji,[4] gathered fresh from fronds of seaweed and preserved in the dried state, were slowly decalcified, stained with borax carmine, and cut in serial transverse sections 6 μ thick. The protoplasm of the chambers was shown deeply stained and surrounded by the lining membrane, which was also stained, but less deeply. The place previously occupied by the calcareous skeleton, however, seemed to be empty of all but balsam. The sections were then treated with methylene blue, which at once revealed the presence of a fine network in the apparently empty space. My friend Prof. Goodrich, who applied this stain for me, then treated the sections with Stephens's blue-black ink, which rendered the network remarkably conspicuous.

On the other hand, specimens of *Miliola*, gathered from Corallines at Lyme Regis, killed with corrosive sublimate and preserved in alcohol, showed after similar treatment scarcely a trace of the intraskeletal network, although the lining membrane was well displayed.[5]

[1] 'Untersuchungen an Foraminiferen: I—*Calcituba polymorpha* Roboz' Zeitschr. f. Wissensch. Zool. vol. lix (1895) p. 219.

[2] 'Ueber die Struktur der Kalkschalen Mariner Rhizopoden' Zeitschr. f. Wissensch. Zool. vol. lxxiv (1903) p. 478.

[3] 'Zur Kenntniss der Thalamophoren' Archiv für Protistenkunde, vol. x (1907) p. 41.

[4] My best thanks are due to my friend, Sir Sidney Harmer, for the gift of these and other specimens.

[5] I am indebted for this and many other specimens to the generosity of my friend, Dr. J. J. Lister.

Of the existence of an intraskeletal organic network there can, however, be no doubt; but the amount of material that it contributes to the skeleton is comparatively small, and it would be scarcely appropriate to speak of it as an organic basis, although this term may be conveniently employed to designate the skeletogenous layers: that is, the lining membrane and included network taken together.

Attempts made to determine the specific gravity of the organic residue by means of a diffusion-column were met by unexpected difficulties: the substance of this residue was apt to swell up, to become 'sticky' and lose its consistency, and the results which were obtained were so divergent as to be of no scientific value, except as showing that the organic basis of the shell cannot be chitin: but this was already known, for Awerinzew in a very valuable paper has not only shown that the basis cannot be chitin, but has referred it to the albuminoids[1] and indeed identified it as a keratin.[2] He also calls attention to the fact that the properties of keratin, as of all albuminoids, are affected by age, and thus furnishes an explanation of the unsatisfactory results which were obtained from my specimens, for they were none of them freshly collected, and some were very old indeed. It may be of interest to add here that an examination under the microscope of the organic basis afforded by these specimens revealed the presence of various impurities, in particular an abundance of minute diatoms of more than one kind. These were removed with fluoric acid; but this treatment caused the keratin to swell up more readily than before, and rendered hopeless any attempt to determine its specific gravity.

Minute Structure of the Imperforate Shell.

When a thin section of *Orbitolites* is examined under a fairly high magnification, such as a No. 7 Fuess, a well-marked fibrillar structure is seen, the fibrils running more or less concentrically round each chamber (Pl. VII, figs. 1 & 3). This structure was first seen and figured by Rhumbler[3] in specimens etched with picric acid; such preliminary treatment is, however, quite superfluous, for the structure is obvious enough without etching, provided that the sections are sufficiently thin. Rhumbler does not pursue the matter further, except to make the inapposite remark that his observation is confirmatory of Awerinzew's description of the crystalline structure of the shell.

In horizontal sections of *Orbitolites* the chambers may be described as bounded distally by arches, and at the sides by the piers of these arches, which in turn rest on the crown of the arches of the zone next succeeding towards the centre. The proximal

[1] S. Awerinzew, *op. cit.* 1903, p. 482.

[2] *Id.* Mitt. Zool. Stat. Neapel, vol. xvi (1904) p. 349, in particular p. 356.

[3] 'Die Foraminiferen der Plankton-Expedition' vol. iii, pt .1 (1913) p. 103 & fig. 29.

boundary is completed by a lateral extension of the bases of the piers on each side, or, when these fail to meet, by the confluence of the arches upon which they rest. The component fibrils run for the greater part parallel with the course of the piers and arches. In some regions, particularly near the base of the piers or pillars and in the upper or under wall of a chamber, the fibrillar is replaced by a minutely granular structure.

In a vertical radial section pillars presenting characters similar to those just described are also present; but frequently several of them are confluent laterally (that is, in a vertical direction) to form a more or less continuous wall to the vertically extended chambers, and frequently also several are aligned along a radius to form a radial strand. The component fibrils of the pillars maintain the radial direction, and where the pillars of one zone meet those of another the ends of the fibrils are opposed along the line of junction. This line corresponds to the boundary between successive zones.

Examined between crossed nicols the primordial chamber presents, like *Globigerina*, a dark cross, but with broader arms and more vaguely defined boundaries: in accordance with this the optical sign is found to be positive, whence we may conclude that the optic axes of the constituent calcitic elements are directed not radially but tangentially.

The surrounding chambers have been studied by Awerinzew (*op. cit.* 1903), who states that the radial walls (pillars) behave as positive uniaxial crystals arranged radiately to the centre, while the concentric walls (arches and wall of annular canals) and horizontal walls behave as similar crystals tangentially arranged: he adds, however, that the subject requires further investigation.

The actual structure of the shell is indeed far too complicated to be brought under so simple a generalization, and exception may be taken to the terms in which it is expressed: for, since all the evidence points to calcite as the only mineral component of the walls, an interpretation of their structure in terms of positive uniaxial crystals would seem to be precluded.

The walls of the chambers, external to the central disc, do not exhibit a dark cross when examined between crossed nicols. Such figures as are observed vary in different specimens and different parts of the same specimens. In offering a description of one of the forms most commonly met with we shall suppose that a horizontal section is so orientated on the stage of the microscope that the axis of one of the pillars coincides with the vertical crosswire of the eyepiece. The figure which is then seen consists of a vertical bar and two curved arms proceeding from it as shown in the diagram (fig. 1, p. 204, and in the illustrations, Pl. VII, figs. 2, 4, & 6). The vertical bar begins above,[1] at the junction

[1] The terms 'above' and 'below' refer here only to the image as seen in the microscope: relative to the organism they should be 'distal' and 'proximal,' or 'outer' and 'inner.'

of two adjacent arches, it then broadens out as it continues downwards through the underlying pillar, and finally narrows again as it proceeds through the crown of the arch upon which the pillar stands. The curved arms are given off, one on each side of the base of the pillar, and follow the curve of the arch along its upper margin. On rotation of the stage these arms remain extinct; and with a rotation of 45° they form with their fellows in the same zone a continuous wavy band, which follows all the undulations of the arches.

In the vertical bar we have straight extinction of horizontal fibrils above and below and of vertical fibrils in the middle; in the curved arms the optic axes must be standing vertical to the plane of the section and transverse to the length of the fibrils.

It may be observed further that the dark areas in the figure just described are not uniformly black, but splashed by illuminated dots and dashes, and conversely the illuminated areas are speckled with dark dots and dashes: an appearance which indicates the existence of fibrils crossing the direction of their fellows, and as well of variously orientated granules.

In this felt-like structure we find an explanation of the porcellanous character of the Imperforate shell: the test is materially continuous but optically discontinuous, or at least heterogeneous, and the entering light, repeatedly refracted and reflected, loses itself in reverberations. Thus the shell is white for the same reason that snow is white. So far as keratin is present it will contribute to this effect.

But, again, may not the honey-yellow colour seen in thin sections by transmitted light be a related phenomenon, the effect of a turbid medium? On this question being put to my friend, Prof. Lindemann, he thought it not unlikely, and suggested a comparison with the sky. Afterwards, when examining under the microscope one of my sections which had always puzzled me by appearing blue instead of yellow, I tried the effect of shading off the light falling upon it from above. The blue then disappeared and the usual honey-yellow was seen by transmitted light. On cutting off the transmitted light and viewing it by reflected light alone, the blue reappeared in greater purity. Thus the comparison would seem to hold, and the shell is yellow by transmitted light for the same reason as the sky is blue by reflected light.[1]

It may next be asked whether particles sufficiently small and numerous to produce this effect are present in the substance of the shell.

Here allusion may first be made to some observations by Awerinzew, who, after heating some *Orbitolites* for two or three minutes in a bath of fused potassium iodide (which melts at

[1] The phenomenon is a very common one; I have observed it in chalcedony both before and after heating to redness, to a less degree in gypsum similarly heated, and to a still higher degree in a film of balsam which had been spread on a glass slide and exposed to the action of fluoric acid vapour.

634° C.), examined them under the microscope, and was then able to observe a globulitic structure which he believed to be original; and he considered that the interspaces between the globulites were originally occupied by the keratin network previously described.

Since calcium carbonate begins to decompose below 634° C. these conclusions seemed to be doubtful. I therefore prepared a thin slice of *Orbitolites*, and, after making sure that it clearly displayed the characteristic fibrillar structure, heated it for half a minute in molten potassium iodide. It was then freed from the potassium iodide, mounted in balsam and examined under the microscope. The globulitic structure was fully displayed, but all traces of the original fibrillar structure had disappeared. This is suggestive of an artefact origin. On the other hand, attempts at measurement of the globulites on the one hand and the granules present in the original structure on the other showed a rather close approximation in size, the granules being slightly the smaller.

Exact measurement was impossible: in the first place the divisions in my eyepiece-micrometer were too widely spaced, and in the next it was impossible to determine precisely the boundary of the object. One division of the eyepiece scale corresponded to a length of 0·0023 mm., and the diameter of the globulites was estimated as about half of this, sometimes more, sometimes less. On the dark field produced by crossed nicols, however, the outlines of both granules and spicules is sharply defined, and their apparent diameter could be precisely measured. It was estimated as one-fifth of a division, or 0·00046 mm., thus corresponding with the wave-length of blue light. This is well within the limit of resolvability (0·00027) but beyond the theoretical limit of visibility. It may be a diffraction effect, as Prof. Lindemann points out; but, even so, it indicates the existence of such particles as theory requires.

The light transmitted by the shell is not a pure yellow, however, but tinged with brown; and Prof. Lindemann suggests in explanation of this that a certain amount of white light may be reflected by the larger granules, whence some resulting blackness, which, added to the yellow, produces a brown shade.

It now only remains to determine, with the aid of a quartz-wedge or a selenite-plate, the direction of the optic axes in relation to the fibrillæ and their disposition in the substance of the shell. Numerous observations show that in some cases the optic axis is coincident with the length of a fibril, but in others it is as definitely transverse.

The transverse direction is scarcely what we should expect in an elongated crystal of calcite, and suggests a comparison with that variety of this mineral which has been named 'lublinite.' This occurs as felt-like intergrowths of minute acicular crystals (not exceeding 0·02 mm. in length) with very oblique extinction, which Quercigh regards as rhombohedral crystals greatly elongated

parallel to a set of edges.[1] Such a felt-like intergrowth occurs in the shell of *Orbitolites*; but, in all cases in which I could accurately observe the extinction of an individual crystal, it was found to be rigidly straight, and thus no explanation is to be sought in this direction. It may be added that the transverse direction of the optic axis has been determined in individual crystals.

All difficulty disappears, however, when we recall that we are dealing with organic products, the outer form of which may be completely independent of their crystalline structure. The spicules of calcareous sponges offer an excellent illustration. This was shown long ago in describing the phenomena of extinction presented by them[2]; and it may now be added that, while the optic axis of a calcareous spicule which gives straight extinction is in some cases directed parallel with the length, in as many others it lies transverse to it.

Of the independence of crystalline structure and organic form we shall presently discover in *Spirillina* an equally interesting example.

Starting now from the fundamental fact that the optic axis is as often transverse to the axis of a fibril as it is longitudinal, I may proceed to complete the description of the intimate structure of the shell, which is more complex and various than might be supposed. I will commence with an account of the structure displayed in horizontal sections.

In all cases abundant fibrils and granules occur throughout the structure with their optic axes directed perpendicularly to the plane of the section. They are especially concentrated, however, in certain areas, as, for instance, the layer already mentioned as giving rise to the curved arms of the black cross shown in fig. 1 (p. 204). In some cases the crown of an arch is formed mainly of three layers, of which that just referred to is the middle one separating an upper layer (*a*, fig. 2) in which the optic axes are, for the greater part, directed across the length of the fibrils (transverse optic axes), from a lower one (*b*, fig. 2) in which they coincide in direction with its length (longitudinal optic axes).

Such an arrangement is, however, by no means constant, or even predominant. The relation of the optic axes to the fibrils seems indeed to be governed by no rule. Thus sometimes, as represented diagrammatically in figs. 3 & 4, the pillars consist mainly of fibrils with transverse optic axes, at others, as in fig. 5, of fibrils with longitudinal optic axes, or again, as in fig. 4, of a core of fibrils with transverse optic axes surrounded by a wall of fibrils with longitudinal optic axes. Similarly, the floor of the chambers

[1] J. Johnston, H. E. Merwin, & E. D. Williamson, *op. cit.* p. 538.

[2] W. J. Sollas, 'On the Physical Characters of Calcareous & Siliceous Sponge-Spicules & other Structures' Sci. Proc. Roy. Dublin Soc. n. s. vol. iv (1885) p. 374.

Fig. 1.—*Diagrammatic representation of a pillar standing on the crown of an arch, showing the fibrillar structure and the polarization-figure seen between crossed nicols.* (× 390.)

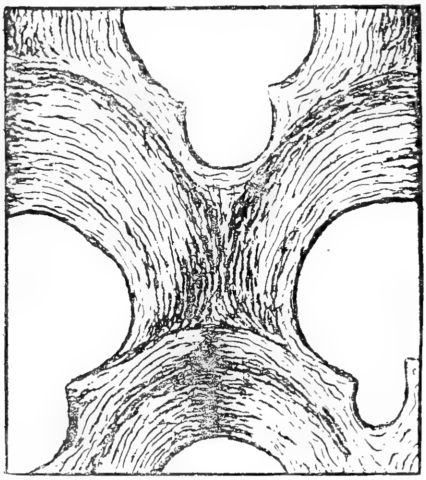


Fig. 2.—*Diagram showing the prevalent direction of the optic axes.*

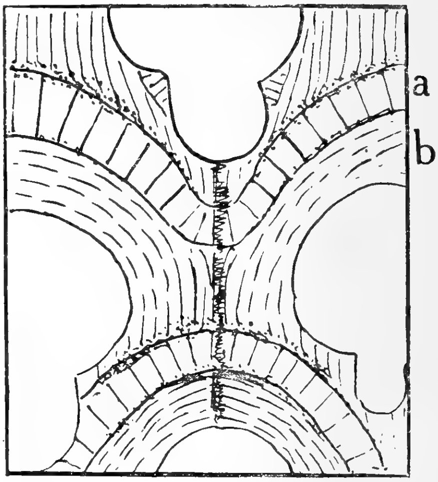


Fig. 3.—*Diagram of the direction of the optic axes, in cases where they are generally transverse to the direction of the fibres.*

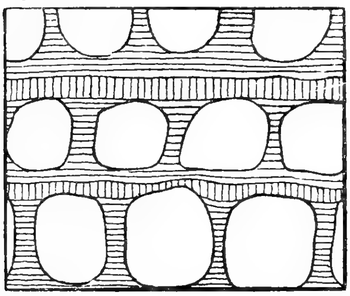


Fig. 4.—*A diagram similar to fig. 3, but with the floor, as well as the roof of the chambers, formed of fibres with transverse optic axes.*

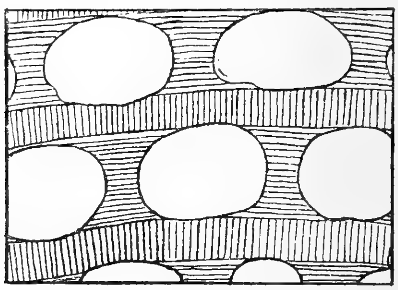


Fig. 5.—*Diagram representing the direction of the optic axes in the section shown as a microphotograph in Pl. VII, fig. 5.*

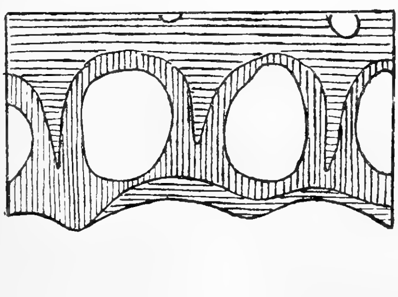
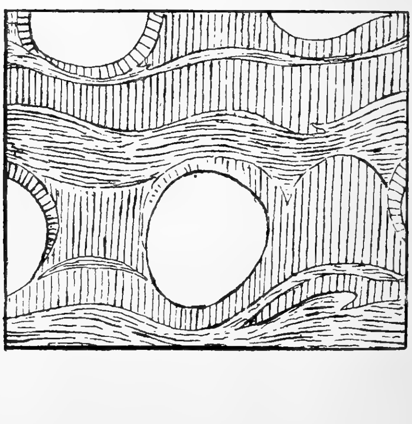


Fig. 6.—*Diagram showing a common case of complicated arrangement of the optic axes.*



is formed of fibrils sometimes with longitudinal optic axes (fig. 3), at others with transverse optic axes. How various the disposition of the axes may be is well illustrated by comparing figs. 3 & 4 with fig. 5.

Turning now to a radial vertical section, we meet with the same composite structure in all parts of the skeleton. In the fibrils of the pillars the optic axis is sometimes predominately longitudinal, but just as often (or more often) transverse, and in the latter case often perpendicular to the plane of the section. When transverse in the plane of the section it represents those fibrils with transverse axes which are cut across in a horizontal section, and when transverse perpendicular to the plane it represents similar fibrils which lie on the plane of a horizontal section. It is scarcely necessary to point out that a transverse optic axis may be orientated at any angle in a plane at right angles to the length of its fibril, and it is probable that they are so orientated in pillars composed of fibrils with transverse optic axes.

The concentric walls in this as in horizontal sections are marked with a zone of a faintly lighter appearance than the surrounding structure when examined with ordinary light, and they are more brilliantly illuminated between crossed nicols. In very thin sections they may sometimes be resolved into two layers, in one of which the optic axes are radial and in the other concentric. The former probably corresponds with the undulating band in horizontal sections which remains dark through a complete rotation between crossed nicols.

It would appear from this very inadequate account that the direction of the optic axis stands in no definite relation to the arrangement of the fibrils; but, however unexpected this result may appear, it is, I believe, in general harmony with the facts presented by many other organisms provided with a calcareous skeleton. It finds additional illustration among the Brachiopoda; the shells of such species as I have examined (*Terebratula maxillata*, *Ornithopsis digona*, *Rhynchonella concinna*, and *Spiriferina walcotti*) consist of fibres of calcite running side by side more or less parallel to the surface, and these, though in close juxtaposition, show an even greater independence in the direction of the optic axis than we have already met with in *Orbitolites*: for in that organism fibres with similarly directed optic axes are associated in groups, while in the Brachiopoda there is no fellowship of this kind, each fibre is a law unto itself.

We have now to consider other forms, and will begin with the Miliolidæ. In young specimens of *Spiriloculina* obtained from Funafuti (*Sp. tenuis?*) the wall is remarkably thin, and so finely granular that it requires a No. 9 objective (Fuess) to resolve it; in consequence it is transparent and almost colourless, only faintly tinged with brown by transmitted light, and only just discernibly

bluish by reflected light. The granules for the greater part share in a common orientation with their optic axes tangential to the wall, both in the embryonal and in succeeding chambers.

In large specimens of a *Miliola* from Lyme Regis the granulation is much coarser, and traversed by scarcely visible clearer streaks. Between crossed nicols these streaks are represented by extremely fine striations, very close and numerous, alternately light and dark when inclined at 45° to the angle of general extinction, and following the course of minute transverse ribs which run round the exterior of the shell. As these striations approach the line along which the wall of the chamber unites with that of an adjacent chamber, they coalesce to form a narrow continuous band. The optic axes of those striations which are illuminated when inclined at 45° to the angle of extinction are mostly transverse to the striations.

In *Peneroplis* (*P. pertusus*)[1] the structure is in general finely granular. The primordial chamber gives a dark cross between crossed nicols, with the optical sign positive: the optic axes must therefore lie tangentially. The ribs show straight extinction, and on rotation through 45° from the position of extinction are at maximum illumination; but the furrows between them show no change, remaining dark at all angles. Probably the wall below the furrows is too thin to affect the light appreciably. Each rib extinguishes as a whole, and when on rotation it restores the light it is uniformly illuminated from end to end, the granular appearance so obvious in ordinary light being then almost abolished. This is strongly suggestive of a continuous crystalline structure. The direction of the optic axis seems to be subject to no law. In some specimens it is parallel to nearly every rib, in others on the contrary transverse. In one and the same specimen it may be parallel in some zones and transverse in others; even in the same zone it may be parallel in some ribs and transverse in the rest; and again in the same rib it may be parallel over one half of the length and transverse over the other.

The septal planes are complex, usually presenting three layers—a middle with the optic axis parallel to the surface and two superficial layers with the optic axis transverse, or the direction of the optic axes may be reversed.

The structure of *Cornuspira* (*C. carinata*) is also finely granular. The primordial chamber and the immediately surrounding whorls, owing to their thin walls and the absence of involution, can be examined under fairly high powers without any preparation beyond mounting in balsam. Between crossed nicols they give a well-marked cross, extending from the primordial chamber outwards. The optic sign, observed in four specimens, is negative, and thus, as an exception to the general rule, the optic axes of the crystalline

[1] Here I desire to express my obligation to my friend, Mr. E. Heron-Allen, F.R.S., who has helped me in many ways, especially by the gift of rich material for study.

particles must be directed radially. In the outer whorls this direction is often reversed, and the axes are tangential. The thin walls of the outer whorls possess a structure which is best revealed with the aid of the selenite-plate: it appears as a fine transverse striation due to the alignment of granules having the same optical orientation; the optic sign may be longitudinal or transverse, more commonly transverse. With non-polarized light the striation is but faintly suggested, though occasionally a single stria is sufficiently obvious.

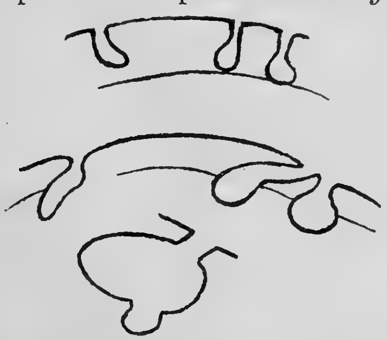
The marginal wall consists of a middle layer which forms the greater part, nearly the whole, having, in the outer whorls at least, the optic axes tangential, and two superficial layers, an inner and an outer, in which the optic axes are radial. The lines of growth are visible between crossed nicols, they curve obliquely forwards, as though the opening of the mouth were rostrate. Sometimes a line of growth is emphasized by the extension along it of the inner layer, which may traverse the whole thickness of the wall and become confluent with the outer layer.

Spirillina stands in remarkable contrast with the preceding forms; its shell is indeed fertile in surprises. It is and has long been regarded as a member of the Perforata, a position which its strangely vitreous character would suggest. As such I have always regarded it, and was therefore quite unprepared to find that it might be otherwise than it seems.

The fine series of *Spirillina*, numerous in specimens and species, on which my observations are based, I owe to the generosity of Mr. Heron-Allen.

If any of the forms of *Spirillina* are perforate, it is surely *Sp. vivipara*, in which the apparent pores are as a rule so abundantly and uniformly distributed: yet they are characterized by a strange inconstancy, sometimes so few as to be easily counted; Rhumbler, for instance, mentions one example in which there are only nine, and in one in my possession there appear to be none. In *Sp. obconica* the pores are not so obtrusive as in *Sp. vivipara*, and out of nine specimens which I have examined no less than seven show no trace of any: whether they are present in the remaining two I am by no means certain. It would thus appear that the 'pores' are adventitious,[1] and this inference would seem to find support

Fig. 7.—*Pseudopores of* Spirillina vivipara *Ehrenberg*.



[Some end within the wall, others extend beyond it, but all end blindly. Upper figure ×275; two lower figures ×330.]

[1] The alternative would seem to be that the same species may include both perforate and imperforate individuals.

from observations made on shells of *Sp. vivipara* which were ground away on the upper side and on fragments of such shells. These reveal numerous pores, which, when traced inwards, are seen to end blindly, sometimes expanding at their termination into a spherical or more or less irregular pouch-like vesicle (fig. 7, p. 207). They present the appearance of having been produced by some boring parasite. Whether all the pores are of this nature is uncertain.

There is a close resemblance between the 'pores' of *Spirillina* and those of *Peneroplis*. In some specimens of *P. pertusus* the 'pseudopores,' as we may term them, are numerous and regularly arranged in rows alternating with the ribs; in others they are completely absent. Further, an examination of the interior of the shell shows that when present they frequently enlarge at the end into vesicles of precisely the same nature as those of *Sp. vivipara*. It may be added that mycelium-like threads burrow through the shells both of *Spirillina* and *Peneroplis*, as they so commonly do in the Foraminifera in general.

Even more surprising is the structure of the shell, both in itself and its amazing variety. In the simplest case, well exemplified in *Sp. obconica*, *Sp. infundibulata*, *Sp. lucida*, and *Sp. vivipara*, the shell is a single homogeneous crystal with, it may be, a few minute grains of calcite sporadically dotted over it, like foreign bodies. The direction of the optic axis differs in different specimens of the same species obtained in one gathering: sometimes it is perpendicular to the plane of the spiral, sometimes more nearly parallel to it, and between these extremes it may take any intermediate position. Here then we encounter another excellent example of the independence of outer form and inner structure in an organic skeleton.

In *Sp. vivipara* we find, in addition to this structure, several others; we meet with forms, for instance, in which fibrils having the optic axis longitudinal make their appearance, and are so arranged that the shell remains illuminated through a whole rotation about its axis: a faint black cross, however, may be detected, and the arrangement of the fibrils is tangential. From this we easily pass to others in which the fibrils are arranged along curved radii, making an angle with the spiral of the shell and giving a spiral cross in the middle which extends over the first whorl: in this case also the optic axis of the fibrils is longitudinal. But by far the most interesting case is that in which the shell consists of an irregular mosaic of crystals. In ordinary light this structure is invisible, part of the shell presenting a granular appearance, and part being apparently homogeneous and devoid of granules; but in polarized light the mosaic is very clearly displayed (Pl. VII, figs. 7 & 7 *a*). The thickness of the wall as seen in optical section is between ·02 and ·03 mm.

In *Spirillina limbata* the shell is more granular than fibrous, and remains illuminated, except for some irregular areas, throughout a complete rotation between crossed nicols; yet in places a negative fibril, tangential for the greater part, extends so far round a whorl that its optic axis passes from tangential to radial.

The fundamental character by which the porcellanous is distinguished from the vitreous shell is its finely granular structure: and all porcellanous shells are imperforate, though it by no means follows that all imperforate shells are porcellanous.

The subdivision of the Foraminifera into the two groups Perforata and Imperforata has lately fallen into disrepute, owing to the discovery among the existing Imperforata of examples which are not devoid of perforations at an early period of their existence. Thus, according to Rhumbler,[1] the embryonal chamber of *Peneroplis pertusus* is distinctly perforate, the pores extending all over it; and not only so, but (according to G. Schacko [2]) pore-canals occur also on the septal sutures of this foraminifer, the perforations being close and fine, and comparable with those of *Nodosaria*. It is further affirmed by Dr. J. J. Lister[3] that the central chamber and spiral passage of the megalospheric form of *Orbiculina* and *Orbitolites marginata* are perforate.

On these rather slender grounds Rhumbler maintains that the terms 'Perforata' and 'Imperforata' are no longer applicable, and Prof. O. Abel[4] proposes as substitutes 'Porcellanea' and 'Vitreocalcarea': of these terms the latter is certainly open to objection, for, since both groups are essentially calcareous, it is not only redundant but to some extent misleading.

On the general question of classification there is room for difference of opinion, and I may commence such observations as I have to make by calling attention to the three isomorphous genera, *Cornuspira*, *Spirillina*, and *Ammodiscus*, which (with the doubtful exception of *Spirillina*) are devoid of perforations and yet respectively porcellanous, vitreous (though in an unusual manner), and agglutinating. Thus the imperforate character would seem to be more constant than the structure or composition of the shell.

Unfortunately, the palæontological record affords less information than we could wish, but it may be remarked that Rhumbler's attempt to derive the calcareous from the arenaceous Foraminifera is directly opposed, so far as it is based on palæontological evidence, by Mr. F. Chapman's account of the oldest known Foraminifera which occur in the *Lingula* Flags of the Cambrian System. All the forms described by Mr. Chapman are calcareous and vitreous, such as *Spirillina* and various representatives of Carpenter's family, the Lagenidæ.

On entering the Carboniferous System we encounter both vitreous and porcellanous forms; the latter indeed reach their culmination in the remarkable genus *Fusulina*. The shell of this foraminifer

[1] 'Die Perforation der Embryonalkammer von *Peneroplis pertusus* Forskal' Zool. Anz. vol. xvii (1894) p. 335 (Lit.).

[2] 'Perforation bei *Peneroplis*' Archiv f. Naturgesch. 49. Jahrg. vol. i (1883) p. 451.

[3] 'Foraminifera' in E. Ray Lankester's 'Treatise on Zoology' pt. 1 (1903) fasc. 2, note on p. 95.

[4] 'Lehrbuch der Paläozoologie' Jena, 1920, p. 46.

presents the same minute structure as is met with in fossil Imperforata, such as *Miliola* and *Alveolites*: that is, it is minutely granular, and so imperfectly transparent that extremely thin slices must be prepared for its examination under the microscope. In this particular it presents a striking contrast to associated vitreous forms such as *Archædiscus*; and I am inclined to think that it was the minute structure of the shell rather than the thickness of his slices which led Carpenter to doubt whether it was perforate or not. That it is as completely perforate as any vitreous foraminifer was first shown by Baron Müller, and with sufficiently thin slices anyone may convince himself on this point, the canals being perfectly obvious (whether seen in longitudinal or in transverse section).

Apparently then, *Fusulina* is as typical a porcellanous form as *Alveolites* and as typical a Perforate as *Nummulites*. If so, the distinction between Perforata and Imperforata is deprived of one of the most important arguments in its support.

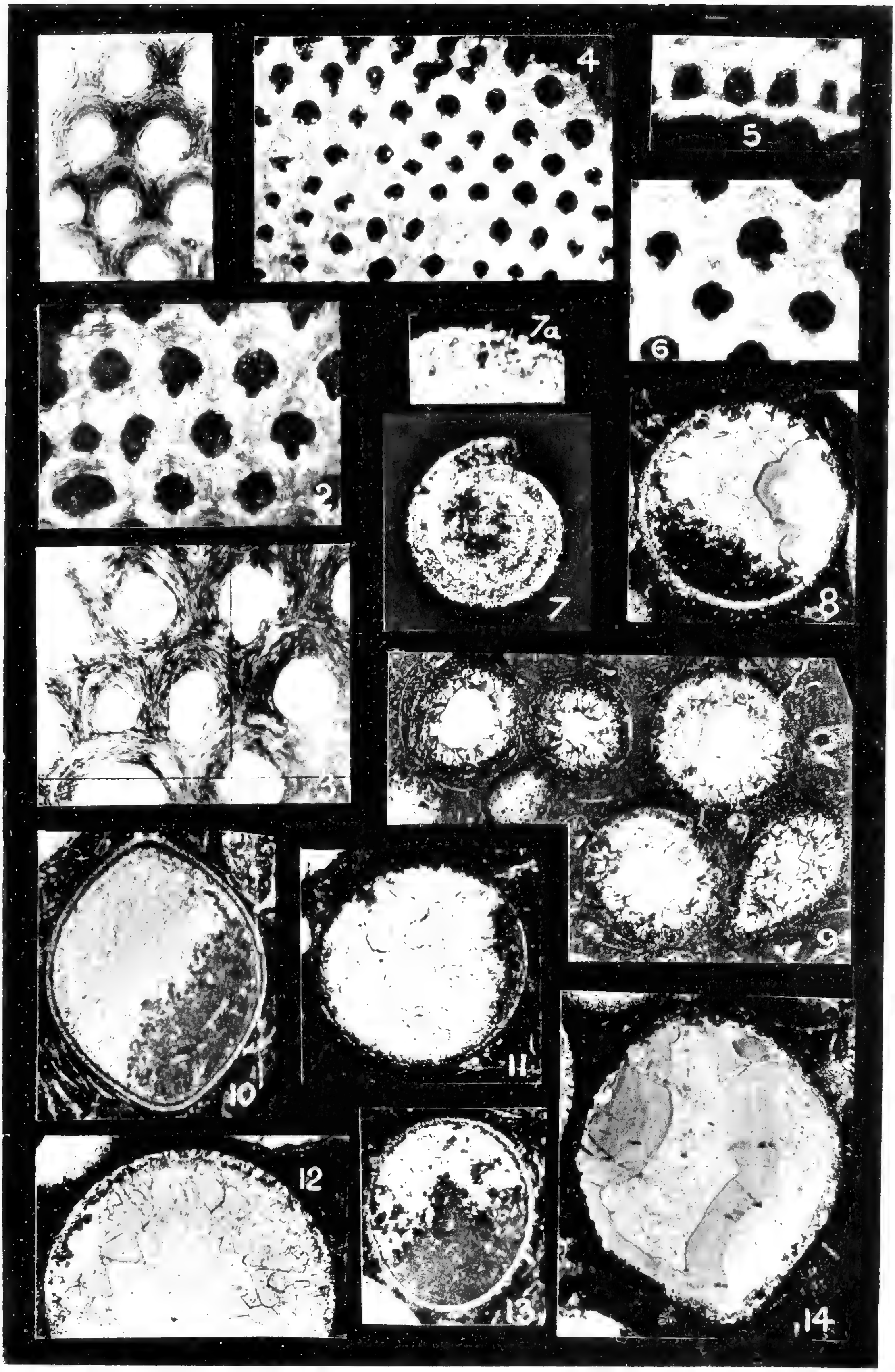
But, since this was written, my attention has been called to some observations by Prof. Henri Douvillé,[1] who, from a study of unusually well-preserved examples of *Fusulina* from Laos, is led to assert that the supposed pore-canals can be seen to terminate blindly and even in pouches. Thus the perforations of *Fusulina* would seem to have no more significance than the blind canals of *Peneroplis*.

A possible objection however may be raised here; it has repeatedly obtruded itself on my mind when reflecting on the supposed pores of *Spirillina*. Is it certain that all the perforations of *Fusulina* are of the same nature? If they are, then it becomes impossible to suppose that they are produced by external parasites, and interesting questions suggest themselves as to the relation of the tubulations to the animal,—how they arise and are maintained, what is their function, and so forth.

Returning now to the problem with which we set out—the taxonomic position of *Saccammina carteri*—we may first enquire how far the structure of various foraminifera is preserved in the fossil state.

The Perforata generally retain their structure, even when traced far back into the remote past and under very various conditions of environment. Occasionally, however, examples may be met with in which the perforations have disappeared and the wall has been converted into a mosaic, one crystal thick, with no remaining traces of the original structure. *Nodosaria* from some localities in the Upper Lias affords an example, but the same genus from other localities of the same age preserves to a considerable degree its original characters. In the Cambrian System the Nodosaridæ can only be determined by their form.

[1] 'Les Calcaires à Fusulines de l'Indo-Chine' Bull. Soc. Géol. France, ser. 4, vol. vi (1907) pp. 576–87.



W. J. S. photomicro.

SACCAMMINA CARTERI BRADY

The Imperforata retain their structure with similar persistency. Thus the *Miliola* of the 'Calcaire Grossier' and Leitha-Kalk scarcely differ in this respect from existing forms, and the same is true of species belonging to this genus, which occur in the phosphatic nodules of the Cambridge Greensand.

The foraminifera which are associated with *Saccammina carteri* in the thin slices I have examined include porcellanous forms, such as *Endothyra*, which retain their original structure with but slight indications of mosaic growth, and vitreous forms, such as *Archædiscus*, which still display their characteristic Nummuline perforation. Both offer a striking contrast to *Saccammina carteri*, and consequently the mosaic structure of its wall may be regarded with great probability as being original.

The fossil may, then, have been an arenaceous form, but there is much to suggest that it was not. Such irregular fragments of calcite as now form the mosaic of its wall do not occur in the muddy part of the *Saccammina* Limestone, and are not likely to have formed part of the ooze of the sea-floor on which the animal lived; and, what is more important, we have already discovered in an example of *Spirillina vivipara* a mosaic structure not unlike that which occurs in *Saccammina carteri*. It is possible, therefore, that the alliance of this fossil is rather with the Calcareous than the Arenaceous Imperforata. That it should bear a name which identifies it, perhaps on insufficient evidence, with a living genus is unfortunate and may lead to confusion. To avoid this, I propose to make the least possible change by calling the genus *Saccamminopsis*.

In conclusion, I should like to express my warm thanks to my friend and colleague, Mr. T. Vipond Barker, for the kindly assistance which I have received from him in the course of this investigation.

EXPLANATION OF PLATE VII.

Fig. 1. Part of a horizontal section of *Orbitolites complanatus* showing the fibrous structure of the walls. × 90. (See p. 199.)

2. A similar section photographed between crossed nicols. × 90. (See p. 200.)

3. A similar section more highly magnified. × 140.

4. A similar section of a larger area, between crossed nicols. × 55. (See p. 200.)

5. A similar section showing, as a thin black line, a layer parallel to the wall of the chamber, which remains extinguished between crossed nicols during a complete rotation of the stage. × 140. (See p. 205.)

6. Part of a horizontal section between crossed nicols. × 90. (See p. 200.)

Figs. 7 & 7 *a*. *Spirillina vivipara* Ehrenberg, seen in optical section; fig. 7×54, fig. 7 *a*×95. (See p. 208.)

Fig. 8. Section of *Saccammina (Saccamminopsis) carteri*, showing below the included matrix (black), on the right a quartz-mosaic, ending in a border of chalcedony; this is sharply bounded by calcite which completes the infilling of the interior. Except where it is in contact with the included matrix, the structure of the shell is destroyed by silicification. ×16. (See p. 195.)

Fig. 9. Section of the Elfhills Limestone with included 'Saccammina.' The test of the 'Saccamminas' is replaced by greenish-yellow quartz, shown as the dark outermost zone; this is succeeded by a zone of calcite-crystals, and the central area is occupied by quartz. $\times 8$. (See p. 195.)

10. Section of 'Saccammina' with the wall sharply defined by a lining of carbonaceous matrix; the rest of the cavity is filled partly with matrix, partly with calcite. $\times 16$. (See p. 194.)

11. Similar to fig. 10. $\times 16$.

12. Section of 'Saccammina' showing the wall replaced by quartz, containing black granules; next a zone of calcite with the points of the crystals directed inwards, and finally quartz which completes the infilling. $\times 16$. (See p. 195.)

13. Similar to figs. 10 & 11. $\times 16$. (See p. 194.)

14. The shell is replaced by quartz, which includes particles of matrix; quartz also has grown inwards as a mosaic which is bounded by agate-like chalcedony. The remaining space in the middle is filled with calcite. $\times 16$. (See p. 195.)

Discussion.

Dr. R. L. Sherlock enquired whether the Author could explain the brown colour shown by the imperforate foraminifera when viewed under the microscope by transmitted light. In thin sections of limestones the imperforate foraminifera show a colour that varies somewhat in different forms, and in some cases resembles that of a flake of biotite similarly viewed. The discovery that these shells are composed of calcite explains the fact of their persistence in some limestones, such as the raised coral-reefs of Fiji, where the aragonite organisms have disappeared. The paper was both interesting and valuable.

Dr. Stanley Smith remarked that in Northumberland, the type-locality of *Saccammina*, that foraminifer is to be found in several limestones as isolated specimens; but it forms two very conspicuous bands—one, in the south of the county in the Four-Fathom Limestone, the other in the north of the county in the Acre Limestone, which lies immediately below the Four-Fathom Limestone. The bands vary up to 3 feet in thickness, and in the northern area the matrix in which *Saccammina* is embedded has often perished to a great extent, so that the bands bear some resemblance to a thick layer of fossil wheat, as exposed in weathered sections.

The Author thanked those present for the manner in which his communication had been received.

10. *The* LITHOLOGICAL SUCCESSION *of the* CARBONIFEROUS LIMESTONE (AVONIAN) *of the* AVON SECTION *at* CLIFTON.

By SIDNEY HUGH REYNOLDS, M.A., Sc.D., F.G.S., Professor of Geology in the University of Bristol. (Read January 5th, 1921.)

[PLATES VIII–XIV.]

CONTENTS.

[NOTE.—The cost of certain of the illustrations and of preparing thin rock-sections, some 200 in number, examined in connexion with this paper, was defrayed by grants from the University of Bristol Colston Society. The numbers (A 11, etc.) refer to slides in the University collection.]

I. INTRODUCTION AND PREVIOUS WORK.

ALTHOUGH a very large amount of information concerning the lithology of the Carboniferous Limestone is now available, that of no section has hitherto been described in detail, and it seemed that a full account of the rocks of the classical Avon Section might prove of value. The first full account of the composition or structure of one of the rocks of that section was W. W. Stoddart's description of the 'Bryozoa-Bed'[1] ('Microzoal Bed') in 1861 and 1865. In one of his papers on the Geology of the Bristol Coalfield, he[2] further gave a considerable amount of information concerning the Avon rocks.

Sorby,[3] in his Presidential Address to the Geological Society in 1879, briefly alluded to some of the oolites from the Avon Section, but it was not until Mr. E. B. Wethered turned his attention to the subject that any detailed work was done. Mr. Wethered's investigations referred, on the one hand, to the chemical and mineralogical features, and on the other, to the faunal and microscopical characters. His paper on 'Insoluble Residues

[1] Ann. & Mag. Nat. Hist. ser. 3, vol. viii (1861) pp. 486–90; also Geol. Mag 1865, pp. 83–85.

[2] Proc. Bristol Nat. Soc., n.s. vol. i (1874–76) pp. 313 *et seqq.*

[3] Q. J. G. S. vol. xxxv (1879) Proc. p. 86.

obtained from the Carboniferous Limestone Series at Clifton'[1] dealt with the former subject, while that 'On the Occurrence of the Genus *Girvanella* in Oolitic Rocks, & Remarks on Oolitic Structure'[2] contains a full description and analysis of the several oolitic bands occurring in the Avon Section. A fairly full account of the microscopical structure of many rock-types is also to be found in his paper on 'The Building of Clifton Rocks.'[3] G. F. Harris[4] also described and figured an oolite from the Avon Section, the example being from 'near Clifton Bridge' and probably from D_1.

Other papers alluding to the calcareous algæ or other somewhat obscure organisms, the remains of which are found in these limestones, are one by Mr. Wethered, in which *Mitcheldeania*[5] is described; a second by the same author dealing with *Calcisphæra*[6]; and one by H. A. Nicholson,[7] in which descriptions are given of *Mitcheldeania*, *Solenopora*, and *Girvanella*. Prof. E. J. Garwood's[8] addresses and papers describe a number of these lowly organisms, and give further references to the literature of the subject.

The lithological succession was broadly described in Vaughan's classical paper on 'The Palæontological Sequence in the Carboniferous Limestone of the Bristol Area'[9]—this will be referred to in the following account as 'Bristol paper.' A much greater amount of lithological detail is contained in Vaughan's paper on 'The Avonian of the Avon Gorge,'[10] referred to below as 'Avon paper.' Two papers by Mr. E. E. L. Dixon are of the utmost importance in any discussion of Carboniferous Limestone lithology. The first of these is his account of dolomitization,[11] the second is contained in a paper by him and Vaughan on the Carboniferous succession in Gower.[12] In this a full description is given of many lithological types which are met with in the Avon Section as well as in the Gower peninsula. In particular, the shallow-water deposits which are so characteristic of much of the lower *Cleistopora* Beds and of the *Syringothyris* and *Seminula* Beds are described by Mr. Dixon

[1] Q. J. G. S. vol. xliv (1888) pp. 186–98.

[2] *Ibid.* vol. xlvi (1890) pp. 270–74.

[3] Rep. Brit. Assoc. (Bristol) 1898, pp. 362–63, reprinted in Geol. Mag. 1899, pp. 78–79.

[4] Proc. Geol. Assoc. vol. xiv (1895–96) pp. 76–77 & pl. iv, fig. 8.

[5] Geol. Mag. 1886, pp. 535–36.

[6] Q. J. G. S. vol. xliv (1888) Proc. pp. 91–92.

[7] Geol. Mag. 1888, pp. 15–24.

[8] Rep. Brit. Assoc. (Birmingham) 1913, pp. 453–72: reprinted in Geol. Mag. 1913, pp. 440, 490, 545; also 'Some New Rock-building Organisms from the Lower Carboniferous Beds of Westmorland' *ibid.* 1914, pp. 265–71.

[9] Q. J. G. S. vol. lxi (1905) pp. 181–307.

[10] Proc. Bristol Nat. Soc. ser. 4, vol. i, pt. 2 (1906, issued for 1905) pp. 87–100.

[11] 'Geology of the South Wales Coalfield: pt. viii—The Country around Swansea' Mem. Geol. Surv. 1907, pp. 13–20.

[12] Q. J. G. S. vol. lxvii (1911) pp. 477–567.

as 'lagoon-phase deposits,' and the conditions under which they accumulated are discussed in detail. Vaughan's later papers often refer to the Avon Section, and contain a record of the development of his opinions concerning it. Thus, in the Brit. Assoc. Report (Winnipeg, 1909) on 'The Faunal Succession of the Lower Carboniferous (Avonian) of the British Isles,' Table II gives his views as to phasal equivalents of the Avonian and the physical conditions under which the rocks accumulated, and these views are further developed in the Burrington paper[1] (1911). In this paper several rock-types are described and figured which are characteristic also of the Avon Section. Miss M. B. Chapman,[2] in the course of her enquiry into the mode of origin of the purer limestones, has analysed a number of rocks from the Avon Section; and Mr. L. M. Parsons's[3] paper on 'Dolomitization & the Leicestershire Dolomites' is of much interest, in view of the widespread dolomitization of the Avon rocks. Lastly, a brief account of the Avon lithology is contained in a paper read before Section C at the Bournemouth meeting of the British Association for the Advancement of Science. An abstract was reprinted in the 'Geological Magazine'[4].

The following account deals primarily with the exposures on the right bank of the Avon; but those on the left bank are briefly mentioned, and are described when any particular horizon is badly exposed on the right bank.

While, at the time of the publication of the Bristol and Avon papers, Vaughan drew the line between the Upper and the Lower Avonian at the top of the *Syringothyris* Zone, it later became clear that C_1 was more closely related to γ and C_2 to S_1, and that the dividing-line should be drawn in the middle of C. The reasons for this are stated in the Gower paper, pp. 542–43, and in the Burrington paper, pp. 307–308.

Vaughan's latest views on the correlation of the rocks of this horizon are contained in his paper on the 'Correlation of Dinantian & Avonian'[5]. In this paper he revives the term 'horizon Δ,' first used in the Avon paper, and extends it to include all the strata from Upper C_2 (*laminosa* dolomites) to Lower S_1. As the present paper is not concerned with questions of correlation, but deals solely with the lithological succession, and also in view of the frequent references to the 'Bristol' and 'Avon' papers which it contains, it has seemed best to describe the rocks under Vaughan's original subdivisions. The quarries are referred to under the names or numbers adopted by Vaughan. Topographical details are only given in cases where they are not likely to be obliterated by later quarrying operations.

[1] Q. J, G. S. vol. lxvii (1911) pp. 385–88.
[2] Geol. Mag. 1912, pp. 498–503.
[3] *Ibid.* 1918, pp. 246–58.
[4] *Ibid.* 1919, pp. 523–24.
[5] Q. J. G. S. vol. lxxi (1915) pp. 1–49.

II. Description of the Rocks.

(A) The *Cleistopora* Beds. (Thickness=about 463 feet.)

(1) The *Modiola* Shales, Km. (Thickness=about 83 feet.) Extent, from the base of the section to the 'Bryozoa-Bed.' There is a double section of these rocks, one in the upper, one in the lower, Avonmouth railway-line. The latter is the better one, and will be here described. The rocks are a transitional series from the Old Red Sandstone, and were clearly accumulated under shallow-water conditions, as is shown by (i) the character of the organisms, (ii) the frequent rounding of the fragments by rolling, and (iii) the occurrence of penecontemporaneous brecciation (dessication-breccia). The actual passage from the Old Red Sandstone to the Carboniferous is bricked up.

(*a*) The Lower Beds.—The prevalent lithological type of the lower part of the *Modiola* Shales is sandy, often calcareous shale, passing into calcareous grit or gritty limestone, according to whether siliceous or calcareous matter predominates. There are also near the base of the section several bands of gritty argillaceous rock wherein the lime is aggregated into nodules, which sections show to contain the probably algal structure described by Gürich as *Spongiostroma* (A 1, A 3). Other rocks consist of sandy and argillaceous material crowded with ostracods, alternating with narrow calcareous bands full of the alga *Mitcheldeania* (Pl. X, fig. 1) sometimes associated with *Ortonella*. These algal layers (see Pl. VIII, fig. 2) sometimes show brecciation. Bryozoa are present in some sections (A 10, 11, 12). *Solenopora* (Pl. X, fig. 2), though found by Prof. E. J. Garwood[1] and occasionally present in the sections examined, does not appear to be common.

Definite bands of limestone several inches thick are also met with as one ascends the series, and while in most cases crinoids are the predominant components, in others brachiopods are the limestone builders. Sometimes the small shell, crinoidal, and other fragments are thoroughly rounded, perhaps in part by solution, in part by rolling (A 14, Pl. X, fig. 3). Some bands of compact black limestone are, however, chiefly composed of ostracods, sometimes associated (A 1, A 5) with small Spirorbid annelids, gastropods, and calcareous algæ. Small gastropods are also a characteristic feature of certain levels in the *Cleistopora* Beds of Burrington and Portishead. Miss M. B. Chapman,[2] who gives an analysis of a limestone from this level, records the presence of sponge-spicules. Ostracods are plentiful in almost all the rocks, whatever their lithological character.

[1] Rep. Brit. Assoc. (Birmingham) 1913, p. 466. The statement as to its occurrence, in the abstract of a paper read by the present author at the Bournemouth meeting of the British Association for the Advancement of Science (Rep. Brit. Assoc. 1919, p. 188, and Geol. Mag. 1919, p. 523), requires modification.

[2] Geol. Mag. 1912, p. 499.

Small phosphate-nodules occur in certain bands (A 8), and Mr. Dixon informs me that similar nodules are met with in the Lower *Modiola* Shales of Tenby.

(*b*) The Upper Beds.—The upper 30 feet immediately below the Bryozoa-Bed are well exposed, and consist mainly of thinly-bedded, often sandy and rubbly limestone with reddish shaly partings. One limestone-band is, however, as much as 4 feet thick. Certain bands in Km show some dolomitization; but it is not a characteristic feature of the rocks of this level.

About 15 feet below the Bryozoa-Bed in the upper Avonmouth line is a well-known band of argillaceous limestone, crowded with *Athyris royssii* and containing Spirorbid annelids and bryozoa. This band has not been observed in the lower line.

On the left bank of the Avon the *Modiola* Shales are well exposed, both in the railway-cutting and by the riverside.

The following is the succession in the riverside exposure:—

	Thickness in feet	*inches.*
12. Bryozoa-Bed.		
11. Thinly-bedded sandy and rubbly limestone, with reddish shaly partings	5	0
10. Shale, with two prominent but impersistent bands of black limestone at the base	14	0
9. Black limestone	1	0
8. Argillaceous limestone overlain by shale	1	6
7. Massive, finely crinoidal limestone	4	6
6. Shale with thin irregular limestone-bands, some of which are crinoidal, some algal; while in others Spirorbid annelids, lamellibranchs, and small gastropods are seen on the weathered surface	15	0
5. Limestone, mainly algal, alternating with partings of sandy shale. One bed of algal limestone shows brecciation. The highest bed is ripple-marked	7	0
4. Sandy shale	5	0
3. Limestone	1	2
2. Shale	6	0
1. Green micaceous mudstone with fish-scales, overlying reddish shale regarded as the top of the Old Red Sandstone	1	3
	61	5

The most interesting bands in the above section are Nos. 5 & 6, in which the algal nodules show up well on the weathered surface (see Pl. VIII, fig. 1). In the three rock-slices examined *Mitcheldeania*, associated sometimes with *Ortonella*, forms narrow bands alternating with fine sandy material.

Another fine section of the whole of Km is seen in the railway-cutting. The development is less shaly than that on the right bank of the Avon. Immediately below the Bryozoa-Bed is a band of grey crinoidal limestone which does not occur on the right bank.

In the Burrington and Failand sections there is a strongly-marked band of coarsely oolitic limestone at this level, and at Abbot's Leigh, less than a mile and a half away, the oolitic character is conspicuous. No oolitic band has, however, been observed at this level in the Avon Section.

(2) The 'Bryozoa-Bed,' horizon *a*. (Thickness = about 25 feet.)—This is well exposed in both the upper and the lower Avonmouth lines. In the former it shows up very prominently below the arches at the mouth of the tunnel through Durdham Down. The Bryozoa-Bed is also well seen in the riverside exposure and by the road.

W. W. Stoddart,[1] from an examination of the insoluble residues, gave the first description of the Bryozoa-Bed ('Microzoal Bed'), figuring gastropods, ostracods, bryozoa, and crinoids from it. Mr. E. B. Wethered[2] recognized the presence of corals, in addition to the organisms described by Stoddart. Mr. E. E. L. Dixon has also described the characters of that bed.[3] The Bryozoa-Bed consists of about six main bands of limestone, separated by shaly partings. It is a red, mainly crinoidal, but partly bryozoal limestone, sometimes very fine-grained, sometimes more coarsely crystalline. A special feature, as has been noticed by previous observers, is the rounding of the small fossils. Bryozoa[4] are very plentiful at certain levels, but absent at others. Quartz-grains are also plentiful in some bands. The hæmatite which gives the rock its characteristic colour is sometimes uniformly distributed as a general stain; but its most characteristic method of occurrence is when the cavities of the bryozoa and small gastropods are filled by it, and the crinoidal ossicles have their structure picked out, while the main part of the rock is only slightly stained.

Some 4 feet from the base of the Bryozoa-Bed is a band showing the peculiar structure first denominated by R. H. Tiddeman[5] 'pseudobrecciation.' As this structure is far more characteristic of the D beds, it will be described more fully when I deal with them (p. 234). In this case the change has led to much separation of iron and some of argillaceous material. A point of interest is that the pseudobrecciation here affects a crinoidal, not (as is usually the case) a foraminiferal, rock.

Immediately above the pseudobrecciated bed is a band of dolomite-mudstone 6 inches thick. This is the most important

[1] Ann. & Mag. Nat. Hist. ser. 3, vol. viii (1861) pp. 486–90.

[2] Q. J. G. S. vol. xliv (1888) p. 190. [3] *Ibid.* vol. lxvii (1911) p. 515.

[4] The bryozoa from the K-beds of the Avon section, and especially from the Bryozoa-Bed, have been generally assigned (as by Vaughan, Bristol paper, p. 188) to the genus *Rhabdomeson*. Prof. J. W. Gregory, however, who kindly examined some sections, writes that one of the organisms 'consists of long angular tubes, very few diaphragms, some acanthopores on the surface, and a cup-like expansion at the distal end. It must be a genus closely related to *Batastomella*, but the genus is hardly determinable without more specimens.'

[5] 'Geology of the South Wales Coalfield: pt. viii—The Country around Swansea' Mem. Geol. Surv. 1907, p. 10.

example of a dolomite met with in the K beds of the Avon Section.

Mr. E. E. L. Dixon[1] discusses the conditions under which ferruginous limestones of the Bryozoa-Bed type accumulated, concluding that they were deposited in shallow water in isolated coastal areas.

On the left bank of the Avon the Bryozoa-Bed is well seen, both in the railway-cutting and in the riverside exposure.

(3) K_1. (Thickness = about 70 feet.)—Only the lower part of K_1 is exposed on the right bank of the Avon, being seen in the lower Avonmouth line. The Bryozoa-Bed is here succeeded by $3\frac{1}{2}$ feet of thinly-bedded sandy limestone, and then comes the well-known 'Palate-Bed,' a gritty crinoidal limestone about 6 inches thick, containing bryozoa, numerous palatal teeth of Elasmobranchs, and rounded nodules of phosphate ('coprolites'). This band is also exposed under the arches near the mouth of the tunnel, on the upper Avonmouth line. On the Palate-Bed rest a few feet of rock, partly consisting of fine calcareous grit with grains of a green mineral (probably vivianite), but passing up into somewhat gritty limestone with crinoids, many brachiopods, and small phosphate-nodules. Then follow 20 feet of ill-exposed shale and thinly-bedded limestone containing abundant brachiopods and ostracods, sometimes associated with crinoids and bryozoa. One band is crowded with bryozoa and small gastropods, and structures believed to be Echinid-spines occur (A 34).

The remainder of the section, as far as the point where a path crosses the railway, is hidden by a wall, and it is at the path that Vaughan (Avon paper, p. 98) drew the line between K_1 and K_2. Miss M. B. Chapman gives analyses of two rocks from this horizon, and records the presence in the insoluble residue of zircon, tourmaline, and much kaolinized felspar.

On the left bank of the Avon the greater part of K_1 is seen in the riverside exposure. A few feet immediately overlying the Bryozoa-Bed are not exposed, and the Palate-Bed is not seen. Then come 11 feet of thinly-bedded limestone with shaly partings; some of the limestones are compact and not obviously fossiliferous, but most are crowded with brachiopods. Two bands near the top of this layer are noteworthy: a lower one full of *Orthotetes crenistria*, the cavities of the shells being occupied by conspicuous white patches of crystalline calcite, and an upper one crowded with *Leptæna analoga*.

Shales and mudstones, 17 feet thick, with subordinate thinly-bedded, compact, and not markedly fossiliferous limestone succeed; then follow perhaps about 20 feet of ill-exposed limestone and subordinate shale. The limestone generally is highly fossiliferous. *Cleistopora geometrica* occurs at this level less rarely than elsewhere in the Avon Section.

[1] Q. J. G. S. vol. lxvii (1911) p. 515.

There are no exposures of this horizon in the railway-cutting on the left bank.

(4) K_2. (Thickness=about 285 feet.)—The lower K_2 beds are not exposed on the right bank of the Avon, being overgrown or hidden by walls. The middle beds are poorly seen in the railway-cutting. The upper beds are better exposed in Press's Quarry[1] (where about 30 feet are seen) and in the adjacent railway-bank. The middle beds consist of highly fossiliferous, thinly-bedded, crinoidal limestone and shale, the shale (which is sometimes gritty) predominating. Ostracods and bryozoa are plentiful, but the prevalent limestone-builders are crinoids and brachiopods.

The upper beds consist of highly crinoidal and brachiopodal limestone, with thin shaly partings. The matrix between the crinoidal ossicles is sometimes partly dolomitized (A 38), but dolomitization is by no means especially characteristic of this horizon. On the other hand, many of the fossils are silicified. Miss Chapman's analyses,[2] three in number, show the presence of magnesia varying in amount from 6·07 to 7·42 per cent.

On the left bank of the Avon a cutting in the woods just north of the northernmost quarry (Quarry 1) gives a good section of some 35 feet of the upper beds. The rocks consist of highly fossiliferous limestone interbedded with shale. Nothing is seen of the middle or lower part of K_2 on the left bank of the Avon, and the horizon, as a whole, is worse exposed in the Avon Section than any other.

(B) The *Zaphrentis* Beds. (Thickness, including Horizons β and γ = about 396 feet.)

[The lithological succession is in close agreement with that of Gower.]

(1) Horizon β. (Thickness=about 20 feet.)—The lowest 20 feet of rock exposed in Press's Quarry, at the base of the precipice below Sea-Walls, are assigned to this horizon, but without definite palæontological evidence to separate it from Z_1. It consists mainly of thickly-bedded massive limestone crowded with crinoids and brachiopods, and with bryozoa not infrequent. Miss Chapman records 9·99 per cent. of magnesia in a rock from Horizon β, but I have not observed any highly dolomitized band. Possibly her specimen came from a band which I regard as belonging to the base of Z_1. As in K_2, there is some silicification of the fossils. A thrust-fault traverses the cliff overlooking Press's Quarry. Near the top of the cliff it runs parallel to the bedding-planes; but, as it passes down, it begins to cut across them, until at the base of the cliff it is inclined to them at an angle of about 35°.

[1] Press's Quarry is a small quarry continuing Black Rock Quarry to the north.

[2] Geol. Mag. 1912, p. 499.

It shifts the outcrop of Horizon β. That horizon is well exposed at the northern end of Quarry 1 on the left bank of the Avon. The lowest beds, which consist of reddish thinly-bedded limestone, form the dip-slope at the northern end of Quarry 1, and are highly fossiliferous.

(2) Z_1. (Thickness = 134 feet.)—The beds that form the massive wall overlooking Press's Quarry are the base of Z_1. They are rather thinly-bedded, and consist mainly of somewhat coarsely crinoidal limestone; sometimes rhombs of dolomite are plentifully distributed in the matrix among the crinoidal fragments. Some bands are laminated, with wisps of shale interbedded in the finely-divided crinoidal material. Much of the lower part of Z_1 is, however, strongly dolomitized, and occasionally shows a cavernous structure on the joint-faces. In one band near the base the dolomitization has a peculiar patchy character, and the sharply-defined boundaries of the dolomitized areas suggest infilling or brecciation. Some of the bedding-planes which form a prominent feature at this horizon are determined by narrow shaly partings crowded with brachiopods, while others occur at the level of bands of compact pale dolomite. Bryozoa are rather plentiful in some layers (A 41).

At a level about half-way up Z_1 there is a band of chert (A 46) due to replacement of the limestone. Sections show that silicification is not complete, rhombs of dolomite being scattered through the chert. No sign of sponge-spicules or radiolaria was seen. The crinoidal ossicles, as is usually the case, show themselves very resistant to the process of silicification. A certain amount of silicification was observed in the Z_1 fossils, both above and below the chert, but less than is the case in most of the local sections of Z_1.

Vaughan took the prominent bedding-plane seen where the path leading to the opening for the tunnel through the Downs bears off, to be at the upper limit of Z_1. Upper Z_1 chiefly consists of crinoidal limestone of the type called 'petit granit' by the Belgian geologists. Sections show that the matrix is largely dolomitized. Bedding-planes covered with the brachiopods *Spirifer clathratus*, *Orthotetes crenistria*, and *Chonetes hardrensis* are very characteristic of Upper Z_1. Patches of crystalline calcite sometimes reaching a diameter of 2 inches are frequent throughout Z_1, especially in the dolomitized beds, and appear to be similar in character to those described by Dixon & Vaughan[1] from the *laminosa* dolomites of Gower, and to be due to recrystallization of calcareous mud. One band of dolomite in the lower part of Z_1 contains numerous patches of quartz. The rocks at the middle of Z_1 are somewhat disturbed, and a thrust-plane is seen to traverse them at a point immediately north of Black Rock Quarry. Miss M. B. Chapman gives two analyses, one of a rock containing

[1] Q. J. G. S. vol. lxvii (1911) p. 483.

2·17 per cent. of magnesia, the other of a dolomitized rock containing 16·76 per cent. of magnesia.

Z_1 is well exposed in Quarry 1 on the left bank of the Avon, particularly in a series of crags near the middle of the quarry where the chert-bed is well seen.

(3) Z_2. (Thickness=about 182 feet.)—These beds form the main part of Black Rock Quarry, and are also seen in the riverside exposure. The rocks of this level are extremely uniform in character, and consist throughout of the same general type as the upper part of Z_1—dark dolomitized limestone crowded with large crinoids (petit granit). The well-cleaved calcite of which the crinoidal ossicles are composed catches and reflects the light, and imparts to this rock-type a most characteristic appearance. Foraminifera and *Calcisphæra* are plentiful in the greyer and less completely dolomitized bands (A 48, 49); but in the prevalent 'black rock' from which the quarry derives its name little has escaped dolomitization, except the large fossils—crinoids, brachiopods, and corals. Dolomitization is very marked in the 'Fish-Beds' which form the top of Z_2 and have yielded the numerous teeth and spines of Elasmobranchs, so well known to collectors.

Z_2 is splendidly exposed in Quarry 2 on the left bank of the Avon, and the top of Z_2, the whole of γ, and the base of the *laminosa* dolomite are seen in the riverside exposure between Quarries 2 and 3.

Mr. E. B. Wethered[1] and Miss M. B. Chapman mention tourmaline and zircon as occurring in the insoluble residue of these limestones. Singularly enough, in view of the widespread dolomitization in Z_2, the rocks analysed by Miss Chapman[2] contained only 1·73 per cent. of magnesia, while her example from Horizon γ contained 10·68 per cent.

(4) Horizon γ. (Thickness=about 60 feet.)—This level is seen in the southern part of Black Rock Quarry and in the riverside exposure. The same type of massive, dark, crinoidal limestone (petit granit) prevalent in Z_2 continues to the top of γ. While, as in Z_2, the bulk of the rock is completely dolomitized save for the larger fossils, there are in γ some grey bands which are little dolomitized and contain abundant foraminifera and *Calcisphæra* (A 50*d*). Patches of calcite, similar to those mentioned above as occurring in Z_1, occur all through Z_2 and γ, particularly in the more highly dolomitized layers. Part of the *Caninia-cylindrica* Bed at the top of γ presents a patchy appearance, owing to little irregular areas of the limestone having to some extent escaped the prevalent dolomitization. Horizon γ is very well seen in the riverside exposure—in fact, better than in the quarry; Zaphrentids, *Syringopora*, and crinoids stand out on the weathered surface.

[1] Q. J. G. S. vol. xliv (1888) p. 190.
[2] Geol. Mag. 1912, p. 500.

On the left bank it is well seen in Quarry 2, in the neighbouring riverside exposure where the band of patchy dolomitization near the top may be noted, and by the road. The upper part is poorly exposed in the railway-cutting south of Quarry 2.

(C) The *Syringothyris* Beds. (Thickness = about 418 feet.)

(1) C_1. The Lower *Syringothyris* Beds. (Thickness = about 183 feet.)

C_1 (*a*). The *laminosa* dolomite. (Thickness = about 93 feet.)—The lower portion of the *laminosa* dolomite forms the highest beds in Black Rock Quarry, and is seen also in the riverside exposure. The upper beds are well seen in the Gully Quarry and in the riverside section, while small exposures occur on the wooded dip-slope between the Black Rock and Gully Quarries.

The lower surface of the *laminosa* dolomite shows suture-jointing with the top of γ, and calcite-patches similar to those of Z are frequent in the lower beds. As in the Gower area, the majority of the rocks were originally crinoidal limestones (A 56), but are nearly always strongly dolomitized. Most bands are converted into uniform dolomite, often enclosing crinoidal ossicles. Occasionally, however, a band occurs in which, though some dolomitization has taken place, the original character of the rock is not obliterated. Certain bands from the lower part of the *laminosa* dolomite show brecciation, the pieces reaching a length of $1\frac{1}{2}$ inches. The pale colour of the *laminosa* dolomite contrasts strongly with the dark colour of the dolomites in Z_2 and γ.

Although, as at Gower, there is no marked break between the *Caninia* Oolite and the *laminosa* dolomite, the line of division may (as in the Avon paper) be taken at the top of the 'Suboolite-Bed' (A 59 *a*), a dolomitized limestone containing abundant *Chonetes* and *Orthotetes*. This bed may be seen both in the quarry and in the riverside exposure, but is best shown in a mass of rock at the top of the bank between the road and the railway.

On the left bank of the Avon the *laminosa* dolomite forms the highest beds of Quarry 2, and is well exposed in the railway-cutting between Quarries 2 & 3. The lower part is also seen by the road and by the riverside. The Suboolite-Bed, not very well seen in the railway-cutting, is well exposed at numerous points in the irregular dip-slope which bounds Quarry 3 on the north, the bedding-planes being often covered with *Chonetes* and *Orthotetes*.

C_1 (*b*). The *Caninia* or Gully Oolite. (Thickness = about 90 feet.)—Exposed in the Gully Quarry, at the northern end of the cutting south of the quarry, by the road, and in the riverside exposure. This band is very uniform in character throughout. The oolite-grains, which are embedded in a matrix of crystalline calcite, are small as compared with those in the D beds. A large proportion of them are formed round foraminifera, others round

crinoidal fragments. Perfect little doubly-terminated quartz-crystals are plentiful in the upper beds (A 63); sometimes the oolitic grains are developed concentrically round them, but more often they are embedded at any point in the grain. Mr. E. B. Wethered [1] gives an analysis and full description of this rock.

The line of junction between the *Caninia* Oolite and the *Caninia* Dolomite is very sharply defined, and at first suggests non-sequence. The somewhat irregular character of the top of the oolite is, however, doubtless due to subsequent solution. Much of the upper part of the oolite has a reddish tinge owing to the presence of iron-oxide, and the solution of the oolite has led to the concentration of the iron along the line of junction.

It is difficult to find fossils in the oolite of the Gully Quarry, chiefly owing to their scarcity, but partly because of the weathered state of the rock; bands of *Orthotetes* and *Chonetes* may, however, be noted in the lower part.

The *Caninia* Oolite is well seen in Quarry 3 on the Leigh Woods side. The lowest bed which is exposed in the cutting, in the eastern wall of the quarry, and at the top of the dip-slope bounding the quarry on the north, is more fossiliferous than is usual with this horizon, *Orthotetes crenistria*, *Chonetes papilionacea*, *Syringothyris laminosa*, and *Michelinia grandis* being readily found.

(2) C_2. The Upper *Syringothyris* Beds. The *Caninia* Dolomite. (Thickness = about 235 feet.)—These rocks form the unquarried strata extending from the Gully Quarry to the Great Quarry. They are well seen in the railway-cutting, and are also visible in the riverside exposure. They are shallow-water deposits, and differ from those of Gower in that the whole series forms part of a *Modiola* phase (the second of those occurring in the Avon Section), while in Gower the upper beds are normal fossiliferous limestones. Evidence of accumulation in shallow water is afforded by the signs of current-bedding which may be seen on some of the joint-faces, and by bands of breccia (doubtless desiccation-breccia) occurring near the base. The rocks consist principally of calcareous shales or mudstones often with ostracods (A 64), alternating with bands which (originally limestone) are now more or less completely dolomitized. They are in the main fine-grained dark-grey or sometimes pink rocks, most of which show no structure in a hand-specimen; but in certain of the less completely dolomitized bands plates of crinoids can be seen. Crinoids, however, do not appear to have been important constituents of the rocks of this level, most of them having originally been calcite-mudstones.[2] Some exceedingly fine-grained and structureless dolomites are probably dolomite-mudstone (A 73 & 85). Some of the limestones

[1] Q. J. G. S. vol. xlvi (1890) p. 271.

[2] The term calcite-mudstone is used in the sense in which it was employed by E. E. L. Dixon (Q. J. G. S. vol. lxvii, 1911, p. 516) who gives a full account of china-stones and other varieties of calcite-mudstone.

were, however, originally fine oolites, and occasionally (A 75 & 78) the original character is little affected; as a rule, however, only 'ghosts' of the oolitic grains remain. Other bands (A 76 & 79) are relatively little dolomitized, and are crowded with foraminifera. *Calcisphæra* too (A 79 & 86) is very plentiful, in some sections (A 74) forming centres round which oolitic grains have developed. The uppermost beds are much like the succeeding S_1 Beds, and include calcite-mudstones with ostracods (A 69 & 89) and argillaceous limestones with algal nodules containing *Mitcheldeania* and *Spongiostroma*. A band about 20 feet from the base is full of ostracods and Spirorbid annelids. A rock-type which is prevalent in all the calcite-mudstones of C_2 and S_1 is now first met with. Hand-specimens of this rock (A 65 & 66) are dark-grey calcite-mudstones, sometimes showing signs of contemporaneous brecciation. Sections, which as a rule include foraminifera and ostracods (Pl. X, fig. 4), are seen to consist of minute, generally rounded patches of structureless calcite-mudstone varying in diameter from about ·1 to ·5 mm. Patches of finer material may be associated with coarser, or the coarse and fine may alternate in layers. The rounded patches may be closely packed together or separated by a little matrix. These little patches of calcite-mudstone may have arisen in two possible ways:—

(1) The 'matrix' or material between them is crystalline calcite, and the isolation of the patches may be due to recrystallization of this 'matrix.' The rock may, in fact, be the exact converse, on a small scale, of the pseudo-breccias (see p. 234), in which the 'fragments' are recrystallized and the 'matrix' between them is less affected. This is probably the most satisfactory explanation of the origin of the structure.

(2) On the other hand, the rock seems to show a close resemblance to a structure described by G. H. Drew[1] from the chalky mud-flats of Florida Keys and the Great Bahia Bank. This he showed to be due to the action of a bacterium (*B. calcis*) on the calcium-salts present in the sea-water. Prof. E. J. Garwood, also, to whom the structure was shown, was inclined to favour the view that it was due to algal activity, even though it does not show any actual algal tissue.

Very little is seen of the *Caninia* Dolomite on the left bank of the Avon; but there are several small exposures in the railway-cutting between Quarries 3 & 4 and one by the road. Miss M. B. Chapman's analyses of *laminosa* dolomite and *Caninia* Dolomite show the presence of 10·32 and 10·96 per cent. of magnesia respectively, while she found none in the *Caninia* Oolite.

(D) The *Seminula* Beds. (Thickness = about 707 feet.)

(1) S_1. The Lower *Seminula* Beds. (Thickness = 160 feet.)—These rocks form the northern part of the Great Quarry. Their base is marked by the entry of Lithostrotiont corals, a band full of *Diphyphyllum* occurring in the last

[1] 'On the Precipitation of Calcium Carbonate in the Sea by Marine Bacteria, & on the Action of Denitrifying Bacteria in Tropical & Temperate Seas' Carnegie Inst. Washington, No. 182 (1914). I am indebted to Mr. E. E. L. Dixon for drawing my attention to this reference.

exposure in the railway-cutting before the Great Quarry is entered. This band (Pl. XIII) is marked as '*Lithostrotion* Band' by Vaughan in pl. v of his Avon paper. The upper limit of S_1 is taken at the outcrop of the lowest[1] *Seminula* pisolite-band. Lithologically the S_1 rocks form one of the most varied and interesting horizons in the whole section, and were clearly (like the underlying Upper C_2 Beds) formed under 'lagoon-phase' conditions. Many bands are partly and some completely dolomitized. For purposes of description the rocks may be divided into two sections: a lower section, S_1 (*a*), predominantly consisting of calcite-mudstones, and an upper, S_1 (*b*), mainly composed of dolomitized *Lithostrotion* limestone.

S_1 (*a*). (Thickness = about 92 feet.)—This section includes the rocks below the 'back slope.'[2] The lowest beds are calcite-mudstones, with several nodular algal layers. The succeeding rocks are chiefly dark-grey (or nearly black) 'china-stones.' As was noted by Vaughan, while the freshly-broken surface usually is dark, they tend to weather very white. Some of them are finely banded and of the type of the 'calcaire zonaire' of Dr. H. de Dorlodot; while the surface of certain layers rises into rounded elevations (Pl. IX, fig. 1), which sections show to consist largely of *Spongiostroma*. These rounded masses, sometimes 3½ inches in diameter, recall a similar structure in the *Seminula-gregaria* Beds of Fawcett Mills, Ravenstonedale. *Seminula* bands are associated with the china-stones, many of which contain *Spongiostroma*, others ostracods or foraminifera. Several of the shaly partings are covered with what are presumably worm-castings, and some of the china-stones contain peculiar vermiform bodies which are probably worm-tubes (Pl. IX, fig. 2). Sections show these 'tubes' to be occupied by loosely-compacted, rounded patches of structureless limestone of the type described above, while the bulk of the rock is formed of the same material closely compacted. There is one marked, but discontinuous, band of *Seminula* Pisolite. At several levels in lower S_1 there are desiccation-breccias, and Mr. E. E. L. Dixon recognized desiccation-cracks in certain of the china-stones. As has been already mentioned, a rock-type very prevalent in the calcite-mudstones of S_1 is that described above (p. 225) and compared with the structure described by Drew from Florida Keys. An example from S_1 is shown in Pl. X, fig. 4.

Between the china-stone level and the 'back-slope' are some 31 feet of strata, consisting of rather thickly-bedded and considerably dolomitized limestone, alternating in the lower part with prominent bands of black shale. These beds are exposed in the slope behind the miniature rifle-range. The most conspicuous shale-band, which is about 3 feet thick and contains abundant

[1] The lowest, that is, with the exception of the discontinuous band mentioned in the next paragraph as occurring in S_1(*a*).

[2] The 'front slope' and 'back slope' (Pl. XIII) are two prominent bedding-planes, thus denominated by Vaughan in his Avon paper, p. 113, and used as datum-lines.

Lithostrotion martini, meets the floor of the quarry just behind the wall of the miniature range. Some 3 feet lower down is another *Lithostrotion* band, and this, with the exception of the *Diphyphyllum* band already described, is the lowest level at which Lithostrotiont corals are found in the section. China-stones are again met with at the level of the 'back slope,' where a band crowded with *Seminulæ* is conspicuous. Many of them show the spiral arms, and others enclose patches of calcite due to the recrystallization of calcareous mud. A big fallen block of limestone at the northern end of the Great Quarry has the bedding-plane (Pl. VIII, fig. 3) covered with elongated bodies, presumably concretionary in character and resembling those described and figured by Prof. E. J. Garwood from the 'Stick-Bed' of D_1 age in the North-Western Province. Sections show this rock to be highly crinoidal, and to contain abundant bryozoa and (?) *Palechinus* spines.

S_1 (*b*). (Thickness = about 68 feet.)—While these rocks are predominantly dolomitized *Lithostrotion* limestones, there is a good deal of variability. The following bands in the lower part may be enumerated :—

(i) Above the 'back slope' is a band, about 11 feet thick, of dark dolomitized limestone, containing basaltiform *Lithostrotion* associated with *Syringopora* and *Lithostrotion martini*. The basaltiform *Lithostrotion* shows up as white patches on the face of the rock. The position of this layer, which is the *Lithostrotion-aranea* Band of Stoddart, is shown in Vaughan's Avon paper, pl. vi.

(ii) The 'front slope' is a bedding-plane of shale covered with *Seminula ficoidea*.

(iii) Some 3 feet above the 'front slope' is a shaly parting (A 104 *a*), alluded to by Vaughan (Avon paper, p. 114) as the 'Trilobite-Bed.' It contains numerous crushed valves and spines (Pl. X, fig. 5) of *Productus semireticulatus* associated with the bryozoan *Heterotrypa* cf. *tumida*, with (?) *Palechinus* spines, and more rarely with pygidia of a small *Phillipsia*. The rock between this level and the 'front slope' is partly dolomitized limestone full of *Seminula* and *Productus semireticulatus*.

Only very thin shaly partings are seen in S_1 above the 'Trilobite-Bed,' and the series thenceforth consists of dark massive limestone, much dolomitized, but not sufficiently so to cause obliteration of the fossils. About 5 feet from the base of this series is the well-known layer containing abundant *Caninia bristolensis* Vaughan, associated with *Lithostrotion*. Foraminifera and bryozoa are also abundant at this level.

Large masses of *Lithostrotion martini* are a conspicuous feature in the upper part of S_1. Mr. E. B. Wethered[1] figures doubly-terminated quartz-crystals formed by secondary growth from detrital quartz, and describes them as abundant in the 'Middle Limestone' ('*Seminula* Beds'), though occurring in both higher and lower beds. Miss M. B. Chapman,[2] who records the presence

[1] Q. J. G. S. vol. xliv (1888) p. 192 & pl. viii, figs. 3–4.
[2] Geol. Mag. 1912, p. 501.

of sponge-spicules, found very little magnesia in the rocks from this horizon; but as much as 14·5 per cent. of insoluble residue was present in one case.

(2) S_2. The Upper *Seminula* Beds. (Thickness=about 547 feet.)—These rocks form the main part of the Great Quarry, and extend almost as far as the New Zigzag path. In the association of standard limestones with rock-types characteristic of a *Modiola* phase (calcite-mudstones and pisolites), the lower S_2 Beds bear a general resemblance to those of Gower. They include four well-marked divisions (see Pl. XII):—

S_2 (*a*). The *Seminula* Pisolites and associated rocks. (Thickness = about 124 feet.)—The base of S_2 is taken at the outcrop of the lowest (see p. 226) band of '*Seminula* Pisolite,' a peculiar lithological type described by Vaughan (Avon paper, p. 93). Sections show that the growths round the *Seminulæ* are mainly composed of *Spongiostroma* (A 111). Two other pisolite-bands occur respectively about 12 and 22 feet above the lowest band. Associated with the pisolite-bands are china-stones and considerably dolomitized limestones containing *Lithostrotion*. The 'pisoliths' (see Pl. VIII, fig. 4) have clearly not all had the same origin. In many cases the pisolith is composed of a series of concentric coats, and is due solely to algal and concretionary growth. In other cases the angular form points to brecciation, as does the fact that many of the larger pisoliths have the concentric coats truncated. In all the pisolitic bands the matrix between the pisoliths or 'fragments' is strongly dolomitized, and the appearance of brecciation may sometimes be due to patchy dolomitization. Silicification affects some of the *Seminulæ* at this level.

Above the calcite-mudstone series come massive compact limestones of the same type as those forming the upper part of S_1, and like them containing very large masses of *Lithostrotion martini* often silicified and associated in the uppermost beds with *Diphyphyllum*. Sections show these rocks to be foraminiferal, and to be sometimes partly dolomitized. *Seminula* bands also occur. These beds extend as far as the grassy slope in the middle of the quarry below the small cave. Above come variable china-stones partly dolomitized, and tending to weather very white. Some of these white china-stones contain vermiform bodies identical with those already mentioned from similar rocks in S_1 (*a*). Associated with the china-stones, which may contain small gastropods and are sometimes strongly banded, is another well-marked band of *Seminula* Pisolite; but the development of both china-stone and pisolite is patchy.

Above the china-stone layer come about 20 feet of compact limestone, partly dolomitized and containing in its upper part three bands of chert. Some 4 or 5 feet of soft dolomite, suture-jointed, much veined, and tending to weather in a cavernous manner, overlie the cherty level, and form a band which is readily

traceable up the quarry-face to the top of the gorge; in this is worn the little cave in the middle of the quarry. The strata at about this level show considerable lateral variability, the massive limestone immediately below the chert in the middle of the quarry passing into china-stones nearer the northern end.

S_2 (*b*). The *Seminula* Oolite. (Thickness = about 58 feet.)—The thick mass of white rock, mainly oolitic, to which Vaughan gave the above name, immediately succeeds, and, as he pointed out, it contrasts with the other strong white oolitic band (the *Caninia* Oolite) in its fossiliferous character. It is somewhat difficult to know what level to take as the top of this oolite, for the oolitic structure becomes very impersistent as the series is ascended. A further difficulty arises from the fact that, wherever it is exposed in the Avon section, the *Seminula* Oolite tends to be bounded by weathered joint-faces in such wise that its characters are very poorly shown.

The lower part of S_2 (*b*) is mainly a fine oolite, with the grains frequently formed round foraminifera. Higher up the series, near the remains of the firing platform, the oolitic character is less continuous, and the rocks are mainly foraminiferal limestones partly dolomitized (A 123). Dolomitization may also affect the oolites, but is not especially characteristic of them. *Calcisphæra* (A 123) is very plentiful in these rocks, and bryozoa are frequent in some bands. Attention may be drawn to three bands showing pieces of oolitic limestone, often rounded and 1 or more inches long, enclosed in the same type of rock, which may be partly dolomitized. The structure is probably due to penecontemporaneous brecciation, followed by the rounding of the resulting fragments by solution. The highest and best exposed of the three brecciated bands meets the eastern base of the screen in front of the firing platform. In the middle band the matrix is dolomitized, while the fragments are not, and have suffered solution more than the matrix. Except for the fact that the rock showing this structure is oolitic and not a calcite-mudstone, and that the fragments are rounded, it is closely comparable with the 'calcaire grumeleux' of Dr. H. de Dorlodot. The term grumelous is adopted by Vaughan [1] for this brecciated type of structure. Somewhat similar rocks occur in the Inferior Oolite of the Stroud district.[2] Mr. E. B. Wethered [3] gives an analysis of an oolite from the Great Quarry. Miss M. B. Chapman [4] also gives an analysis, and records the presence of sponge-spicules and quartz-crystals with secondary growth.

S_2 (*c*). Rocks between the *Seminula* Oolite and the Concretionary Beds. (Thickness = about 240 feet.)—These

[1] Q. J. G. S. vol. lxxi (1915) p. 26.
[2] Proc. Cotteswold Nat. F. C. vol. ix (1890) pp. 100–101 & pp. 388-92.
[3] Q. J. G. S. vol. xlvi (1890) p. 271.
[4] Geol. Mag. 1912, p. 502.

rocks forming the wall at the southern end of the Great Quarry behind the firing platform, and easily accessible on the crags to the south, are chiefly massive foraminiferal limestones, but include *Lithostrotion*- and *Chonetes*-bands, the two fossils being often associated and the matrix between them more or less dolomitized. The rocks of this level further include fairly massive beds of dolomite, and a band of pisolite exposed rather high up the quarry-face. The limestones forming the main part of the big weathered rock-face immediately south of the quarry are also included in this division. This rock-face is a joint-face covered with calcitic and flinty vein-stuff and breccia, to such an extent that little can be made out in the field as to the character of the rocks, and it is even difficult to break off pieces. There are, however, a few exposures in the wooded slope below the rock-face, and others may be reached up the quarry-side. Sections show that the rocks include foraminiferal limestones, sometimes partly oolitic (A 128 *a*); while algal china-stones are frequent, some being partly dolomitized. The upper part of S_2 (*c*) is, however, far better exposed in the series as repeated by the fault.

S_2(*d*). The Concretionary Beds. (Thickness=about 125 feet.)—These rocks are fairly well seen above the wooded slope south of the Great Quarry, and can be followed down to the railway near the New Zigzag path. They are thinner than north of Bristol at Brentry and Sodbury, and the poor character of the exposures has probably caused them to be considered thinner than is actually the case, for the concretionary structure comes on some 55 feet lower than the line marked as the base of these beds in pl. vii of Vaughan's Avon paper. The character of the Concretionary Beds, first mentioned by H. B. Woodward,[1] was fully described by Vaughan in the above-quoted paper (pp. 91–92), but no opinion was expressed as to the origin of the concretionary structure. In the Burrington paper,[2] however, its probably algal nature was recognized. In describing the Belgian rocks Vaughan[3] again refers to these beds, regarding them as a modification of the 'calcaire zonaire' of Dr. H. de Dorlodot.

Many of the 'concretions' strongly resemble the *Girvanella*-nodules described by Prof. Garwood[4] from the D_2 beds of Humphrey Head, Grange. Sections, while, however, confirming the essentially algal character of the concretions, show that

[1] 'On Arborescent Carboniferous Limestone from near Bristol' Rep. Brit. Assoc. (Bristol) 1898, p. 869, and Geol. Mag. 1899, p. 77. The author describes a specimen of the Concretionary Beds from near Brentry, attributing the curving character of the layers to disturbance, not original deposition. He suggests comparison with the Cotham Marble, and adds: 'The appearances are probably due to mechanical disarrangement of the upper layers produced prior to and during the consolidation of the rock, and they suggest a pause in the deposition of sediment.'

[2] Q. J. G. S. vol. lxvii (1911) p. 345.

[3] *Ibid.* vol. lxxi (1915) p. 26.

[4] *Ibid.* vol. lxviii (1912) p. 482.

Mitcheldeania, often associated with *Spongiostroma*, is the prevalent organism (A 186, 187, 188). The Concretionary Beds are interbedded with china-stones, sometimes containing algæ and ostracods, and with white foraminiferal and occasionally oolitic limestone-bands, some of which are partly dolomitized.

The Concretionary Beds are also seen in the riverside exposure nearly opposite the New Zigzag level-crossing.

Series on the right bank as repeated by the fault.—The S_2 beds, as repeated by the Clifton Fault, form the great mass of Observatory Hill (St. Vincent's Rocks), and the section extends from near the bottom of Bridge-Valley Road to a point about 15 yards north of the wall at the base of the Old Zigzag path. The whole of the S beds from a few feet below the base of the *Seminula* Oolite is seen, and the exposures are altogether very much better than in the main section. The lowest beds seen are a few feet of white china-stone, followed by about 10 feet of massive partly-dolomitized limestone, with a double layer of chert in the upper beds. Above this layer, and immediately below the base of the *Seminula* Oolite, is the band of soft dolomite in which the cave of the Great Quarry occurs: this band may be easily overlooked. The *Seminula* Oolite forms practically all the lower part of St. Vincent's Rocks, extending from the fault to the southern end of the section behind Hotwells Station. It is not, as a rule, in a good condition for examination, the exposed surfaces being frequently weathered joint-faces, especially in the station enclosure. The repetition of strata by the small thrust-faults of Observatory Hill gives an exaggerated impression of the thickness of the *Seminula* Oolite.

The lower part of the overlying beds S_2 (*c*) is well seen, if the rocks behind the station enclosure are climbed, and also at the outcrop of these beds south of the station. They consist of massive grey limestone and dolomite, with abundant *Lithostrotion* and *Chonetes* and some chert. The Concretionary Beds, S_2 (*d*), are splendidly exposed in the big rock-face immediately south of the Bridge. The base of this face is formed by the upper part of the underlying strata, S_2 (*c*), and includes china-stones, white oolites, *Seminula* bands, and pisolite-bands; but the main part is formed by the Concretionary Beds, which are seen to be thicker than an examination of some of the other sections might have led one to expect. They consist, in the main, of massive white limestone with numerous concretionary, pisolitic, and *Seminula* bands and a considerable amount of oolite. The concretionary bands show up less than in exposures where the rocks are more highly weathered, and the algal (concretionary) layers are sometimes considerably dolomitized. The best exposure of S_2 (*c*) is in the rock-faces bordering Observatory Hill as the Suspension Bridge is approached. Here the rocks are highly fossiliferous, *Carcinophyllum* being especially plentiful, and algal limestones (*Seminula*-pisolite structure) extremely well seen.

The Concretionary Beds are also well exposed by the roadside from the big rock-face south of the Bridge to their termination at a point just north of the Old Zigzag path. Immediately above the highest concretionary bed is a band of pisolite, and on this rests a band with *Alveolites septosa*; this band is about 40 feet below the base of D_1.

Exposures of the *Seminula* Beds on the left bank.

The main section: S_1.—On the Leigh Woods side nothing is seen of the lower part of S_1, the lowest bed met with being the *Caninia-bristolensis* Bed, which is exposed in the irregular dip-slope forming the northern boundary of Quarry 4. This fossil, associated with *Lithostrotion*, occurs somewhat abundantly on the bedding-planes, which are often determined by red shaly partings. The overlying rocks (top of S_1) are fairly well seen in the western wall of the quarry.

S_2.—The base of S_2 (*Seminula* Pisolite, etc.; S_2 *a*) is very poorly exposed, the rocks being much veined by calcite.[1] The upper pisolites and overlying chert and dolomite are well exposed. The cherts, below which, as in the Great Quarry on the right bank, masses of *Diphyphyllum* are met with, can be followed along the southern face of Quarry 4 to the exposure in the railway-cutting.

The *Seminula* Oolite, S_2 (*b*), which forms the upper part of the western and southern walls of Quarry 4, is in a very bad state for examination, the exposed surfaces being chiefly weathered joint-faces. The northern part of the cutting between Quarries 4 & 5 is in the *Seminula* Oolite, which is well seen. In the southern part of the cutting and in Quarry 5 the variable limestones, S_2 (*c*), which separate the *Seminula* Oolite from the Concretionary Beds are well exposed. They are chiefly massive limestones with *Lithostrotion*- and *Chonetes*-bands, but include also china-stones, dolomites, and oolites. The Concretionary Beds, S_2 (*d*), come on at the top of Quarry 5, and their base is seen in the exposure by the roadside at the tunnel-entrance, the concretionary layers being associated with banded china-stone. The tunnel-slope south of Quarry 5 is formed of Concretionary Beds. A splendid riverside section of part of S_2 and D_1 begins opposite the entrance to that quarry. The lowest beds belong to the *Seminula*-Oolite series, S_2 (*b*), and consist mainly of massive oolite with some foraminiferal limestone, also *Seminula*- and *Productus*-bands. The overlying variable limestones, S_2 (*c*), are better seen than in Quarry 5, and the china-stones include rocks which are white on the weathered surface, but black when freshly broken (like those from S_1 in the Great Quarry). Brecciated and pisolitic bands also occur: in fact, there is a development in the upper beds of all the lagoon-phase rock-types. The Concretionary Beds, S_2 (*d*), which in the quarry-

[1] The red flaggy and shaly material associated with these beds in Quarry 4 is probably due to a Triassic infilling.

section are in the main ill-exposed or inaccessible, are well seen in the riverside section. Attention may be drawn to a marked band of pisolite, the nodules being shown by section to consist of *Mitcheldeania* associated with *Spongiostroma.* Above the pisolite is a strong concretionary band, and this is followed after a break, which suggests non-sequence, by a band containing large masses of *Alveolites septosa.*

The existence of this break suggests that the boundary between S_2 and D_1 be drawn here. All the regular *Seminula*-bed rock-types—concretionary and *Seminula* bands and white banded china-stones—are, however, met with for a further 40 to 45 feet above the *Alveolites* band, and then, although there is no marked lithological break, the D fauna comes on in full force.

Series on the left bank as repeated by the fault.—There are no exposures on the left bank in the immediate neighbourhood of the fault which passes just north of the mouth of Nightingale Valley. South of Nightingale Valley the *Seminula* Oolite, S_2 (*b*), is well exposed in the railway-cutting, by the road, and by the riverside. In the railway-cutting the *Seminula* Oolite is seen from the mouth of Nightingale Valley as far as the southern end of the cutting south of the short tunnel below the Suspension Bridge. The roadside exposure is better than that in the cutting, and includes, in addition to the upper part of S_2 (*b*) [the *Seminula*-Oolite], the main part of S_2 (*c*). The *Chonetes* bands of the lower part of S_2 (*c*) crop out below the Suspension Bridge, while the china-stones and pisolites forming the upper part of S_2 (*c*) are seen in the roadside and riverside exposure, though most of the latter is inaccessible. Very little is seen of the Concretionary Beds, S_2 (*d*), in the railway-cutting, and nothing by the road or riverside.

(E) The *Dibunophyllum* Beds. (Thickness = about 559 feet.)

These rocks extend from the New Zigzag path to the Observatory-Hill fault.

(1) D_1. The Lower *Dibunophyllum* Beds. (Thickness = about 375 feet.)—The D_1 Beds are seen at the top of the slope south of the Great Quarry and in its continuation, the woods of 'Fairyland'; also in the railway-cutting from the New Zigzag path to the mouth of the tunnel behind Point Villa, in Bridge-Valley Road, and in the exposures by the road and riverside as far as Point Villa. D_1 may be taken to commence in the main section at the level-crossing to the Zigzag path. The coarse red oolite, which is very characteristic of the D beds, is referred to by Mr. E. B. Wethered[1] as 'the New Road oolite.' He describes the large oolitic grains of this horizon as consisting in many cases of tubules assigned to *Girvanella ducii.* Only in one case (A 133), a rock

[1] Q. J. G. S. vol. xlvi (1890) p. 272.

from near the base of D_1, have I found *Girvanella* tubules within oolitic grains; and in this case it is clear that the patches of *Girvanella* acted in the same way as the associated foraminifera, in forming nuclei round which the oolitic grains developed: the tubules do not penetrate the layers of the grains. In a rock a few feet lower down (A 131), it is clear that the grains are composed of *Spongiostroma* material. Lower D_1 consists, however, in the main, of massive white limestone crowded with foraminifera. *Endothyra bowmanni* is the commonest, but *Trochammina* and sometimes *Nodosaria* and *Textularia* occur. *Calcisphæra* is also abundant. There are as well bands of compact limestone of china-stone type (A 134) with *Spongiostroma*.

Very characteristic of D_1, though occurring throughout D, are bands of the well-marked rock-type 'pseudobreccia.' This was originally described from Gower by R. H. Tiddeman, and subsequently, more fully, by Mr. E. E. L. Dixon. The rock consists of patches ('fragments') of dark limestone generally crowded with foraminifera surrounded by paler limestone ('matrix'). The limestone of the 'fragments' is partly recrystallized, the change being accompanied by a transference of the contained argillaceous material and iron-oxide to the surrounding 'matrix,' which consequently tends to be reddish, especially when weathered. These rocks have hitherto, in accounts of the Avon section, been grouped under 'rubbly limestones.' It seems, however, that both terms may usefully be retained, though no hard-and-fast line can be drawn between the two rock-types. The term 'rubbly' in the present paper is applied to bands consisting of rounded masses of limestone, often several inches in diameter, embedded in red shaly material. Such bands frequently separate thicker beds of limestone, and probably owe their character to a concretionary or recrystallization process, whereby the lime gathered in nodules from which the iron and shaly material became separated. The frequently discontinuous character of the rubbly beds, perhaps depending on local failure of argillaceous material, is shown in Pl. IX, fig. 4.

In the railway-cutting four well-marked bands of pseudobreccia are seen in the lower part of D_1. They are, however, so much weathered, that the contrast between 'fragments' and matrix does not clearly show. In the little cutting, however, made for the approach to the platform north of the tunnel, there is an interesting section, including an excellent exposure of unweathered pseudobreccia.[1] The highest band in this little section affords an instance of a 'rubbly' bed.

Pseudobrecciation, though commonest in foraminiferal limestone, may also occur in oolites. White, mainly non-oolitic limestones and pseudobreccias are seen in both the roadside and riverside exposures north of Point Villa.

The upper D_1 beds seen in the southern half of the railway-cutting behind Point Villa consist in the main of coarse oolites

[1] The appearance of this rock is identical with that illustrated in Q. J. G. S. vol. lxvii (1911) pl. xxxviii, fig. 2.

alternating with thick shales and red grits. There are bands of both oolite and grit upwards of 20 feet thick. The shale-bands, though not well exposed, attain a great thickness.

Attention may be drawn to a band of red non-oolitic limestone full of *Productus hemisphæricus*, which is exposed in the cutting 45 yards north of the tunnel. Specimens from this bed are common in old collections.

The grits, which are finely granular and iron-stained, often contain some calcareous matrix (A 143). One band consists of large oolitic grains mingled with almost equally large quartz-grains (A 151).

(2) D_2. The Upper *Dibunophyllum* Beds. (Thickness =about 184 feet.)—The D_2 beds are well exposed by the road between Point Villa and the fault, and are also seen in the river-side exposures. The upper beds of the Bridge-Valley Road section belong to this horizon. Almost at the base of D_2 is a coarse grit (A 154) enclosing quartz-pebbles an inch long: this is the only example of such a conglomeratic rock met with in the Avon section. Apart from this band, D_2 is almost identical lithologically with D_1, including thick red grits, shales, coarse oolites, and foraminiferal limestones, together with bands of pseudobreccia and rubbly bands containing *Lithostrotion irregulare* (A 161).

At about 25 feet from the top of the D_2 section, as exposed by the roadside at the bottom of Bridge-Valley Road, an interesting band of sandy limestone occurs. The rock is a variety of pseudo-breccia in which recrystallization has led to the concentration of sandy and ferruginous material in the 'matrix'; while in the more usual type of pseudobrecciation it is argillaceous material that is so concentrated. The rock appears to be similar to one variety of the 'Spotted Beds' described by Prof. E. J. Garwood[1] from the North-Western Province. Weathered blocks built into the wall near the bottom of Bridge-Valley Road show the characters of the rock to perfection.

Crinoids, though not abundant in D_2, play a more important part than in D_1, and reach a greater size than in any other part of the Avon Section. Corals are more varied and abundant at certain levels in D_2 than at any other horizon, and are well seen in road-side exposures south of Point Villa. One band is crowded with bryozoa. At certain levels (A 159) there has been some dolomitization, the change particularly tending to affect the matrix between the oolitic grains. The uppermost much disturbed beds seen at the mouth of the tunnel and immediately below the thrust-plane of the Observatory-Hill fault are mainly red shales and thin grits.

Series on the right bank as repeated by the fault.—The lower D_1 beds are well exposed, and extend from a point a few

[1] Q. J. G. S. vol. lxviii (1912) pp. 475–77.

yards north of the Old Zigzag path to the end of the section near the Colonnade. The rocks consist of a lower series of white limestones overlain by rubbly limestone and pseudobreccia with shaly partings. The highest beds are largely coarse oolite. There are good exposures by the sides of the Zigzag path, pseudobreccias being well seen near the top of the path.

Exposures of the *Dibunophyllum* Beds on the left bank.

The main section.—The beds forming the cliff at the top of the tunnel-slope south of Quarry 5 are the base of D_1. The cliff-boundary is determined by a big calcite-vein in the lower part of D_1, and is in a very bad state for examination. There are, however, at the base of the cliff many fallen blocks of D_1, which have separated off along shaly partings, and these form a good collecting-ground. The dip brings the D_1 beds from the top of the tunnel-slope down to the road, near a small padlocked building, where they are well exposed. The prominent bedding-planes south of this building are determined by bands of pseudobreccia, and are mentioned by Vaughan as good D_1 collecting-ground. The D_1 beds are splendidly exposed in the riverside section adjacent to the tunnel-slope, and consist of massive white limestone alternating with pseudobreccias and with red shaly partings containing gigantoid *Producti*. The pseudobreccias form conspicuous bedding-planes covered with *Cyathophyllum murchisoni*, *Lithostrotion*, and less commonly *Alveolites septosa*. Corals are nearly as plentiful in the massive limestone. The riverside exposure affords a section of these rocks over 100 yards long. No more exposures are met with until Quarry 6 is reached, where D_2 limestones, in part grey and massive, in part pseudobrecciated, and in part coarsely oolitic, occur, but could scarcely be in a worse state for examination.

Series on the left bank as repeated by the fault.—The D beds are very poorly exposed by the railway between the Suspension Bridge and Clifton-Bridge Station. Not far south of the bridge there are fair exposures of white limestone with D_1 corals, while farther south the chief exposures are of the massive grit-bands of Upper D_1 and D_2.

III. Changes which have affected certain of the Rocks.

(1) Penecontemporaneous brecciation (desiccation-brecciation) is a characteristic feature of all the *Modiola*-phase rocks. It affects some of the algal bands in Km, and is met with at intervals throughout the *Caninia* Dolomites (C_2) and the whole of the *Seminula* Beds. The most noteworthy bands showing this feature are (1) a coarsely-brecciated band at the base of the *Caninia* Dolomite; (2) the various *Seminula*-Pisolite levels; (3) the bands at the top of the *Seminula* Oolite exposed near the firing platform in the Great Quarry. It is, however, sometimes

difficult to distinguish between true brecciation and pseudobrecciation, where the isolation of the 'fragments' is due to recrystallization.

(2) Pseudobrecciation, as described from Gower by Mr. E. E. L. Dixon, is most characteristic of the foraminiferal limestones of the D beds; but near the top of D_2, as has been already shown, are sandy and ferruginous bands which exhibit an analogous change, while a similar band near the base of the Bryozoa-Bed (see p. 218) may also be grouped as a pseudobreccia.

(3) Dolomitization proves to be considerably more widespread in the Avon rocks than had previously been ascertained. There is a band of dolomite-mudstone in Horizon α (Bryozoa-Bed) at the base of K_1. There has been a little dolomitization at various levels throughout the K beds, but it is not a characteristic feature of this horizon. The matrix of the petit granit of Z_1, Z_2, and γ is almost everywhere dolomitized. The fact that the corals in the *Zaphrentis* Beds resist dolomitization more than the matrix seems to imply that the aragonite was replaced by calcite prior to the dolomitization.

The almost complete dolomitization of Lower C_1 (*laminosa*-dolomite) and of C_2 (*Caninia* Dolomite) has long been familiar. Some of the bands are dolomite-mudstone. There has been considerable dolomitization in the calcite-mudstones of lower S_1 and at various levels in S_2, and in particular the matrix in the *Seminula*-Pisolite bands is much dolomitized. The same is the case with the relatively massive *Lithostrotion* Limestones of Upper S_1 and at various levels in S_2. Oolites tend to resist the change; but there is some dolomitization of the matrix between the grains at various levels in the C_2 and S beds. There is very little dolomitization in the D beds.

The whole question of the dolomitization of the Carboniferous Limestone has been fully discussed by Mr. E. E. L. Dixon,[1] and the conclusions which he reached regarding the Gower rocks seem to be completely applicable to those of the Avon section. Every argument goes to show that the main masses of dolomite are contemporaneous, or resulting from the alteration of the original limestone shortly after its deposition.

IV. *Modiola* Phases of the Avon Section.

The three *Modiola* phases—that is, 'calcareous lagoon-phases' of Mr. Dixon (Km, C_2–S_1, top of S_2) represented in Gower and tabulated by that author (Gower paper, p. 514)—occur also in the Avon Section, and the only feature of general interest in relation to these phases which the present paper emphasizes is

[1] 'Geology of the South Wales Coalfield: pt. viii—The Country around Swansea' Mem. Geol. Surv. 1907, pp. 13–20.—Dolomitization, particularly as affecting the Carboniferous Limestone of Leicestershire, has been discussed by Mr. L. M. Parsons (Geol. Mag. 1918, p. 246).

the very constant association of calcareous algæ with *Modiola*-phase conditions. Comparing the Avon development with that shown in Mr. Dixon's table the following points may be noted:—

First *Modiola* phase (Km).—No conglomerates or oolites occur in the Avon development. Except for the Bryozoa-Bed the Avon rocks are relatively non-calcareous, and pass gradually into the Old Red Sandstone below; but they are sharply marked off from the standard deposits of K_1 above.

Second *Modiola* phase (C_2–S_2).—Thinly-bedded shales and dolomites are more characteristic of C_2 of the Avon than of Gower. The lower S_1 Beds form the most typical example of a calcite-mudstone phase in the Avon Section. About 34 feet of strata, mainly consisting of somewhat massive dolomitized limestone with abundant *Lithostrotion martini*, separate the china-stones and variable rocks of the middle of S_1 from the similar rocks at the base of S_2, but it has been thought best to include the latter beds in the same phase as the C_2 and S_1 Beds.

Third *Modiola* phase (upper part of S_2).—The Concretionary Beds of S_2 form a third *Modiola* phase, but a good deal of massive limestone is interbedded with the algal limestones and china-stones. The base is ill-defined, the top being more sharply marked by the incoming of the D-limestones with their abundant coral fauna.

V. Summary and Conclusions.

Dr. Vaughan's views regarding the phasal conditions under which the rocks of the Avon Section accumulated were stated in his report presented at the Winnipeg Meeting of the British Association, while Mr. Dixon, in his work on the lithology of the Gower succession, fully describes his conclusions, particularly with regard to *Modiola* phases (calcareous lagoon-phases), and compares those in the Gower area with those of the Bristol area (table v). After a detailed examination of the Avon lithology I find myself so fully in agreement with the views of Dr. Vaughan and Mr. Dixon concerning the general conditions under which the Avon rocks accumulated, that it will be unnecessary to repeat these conclusions. The chief points of interest brought out in this paper are:—

(1) The important part played by calcareous algæ as rock-builders in the Avon Section.

(2) The great amount of dolomitization which has affected the *Zaphrentis*-Beds.

(3) The predominance of pseudobreccias in the D beds, the fact that a band of this type occurs at the base of K_1, and that some of the pseudobreccia-bands in D_2 are sandy limestone, instead of, as is usually the case, foraminiferal limestone.

I am greatly indebted to Mr. E. E. L. Dixon, who has drawn my attention to many points in the field which might otherwise have been overlooked, and has given me the benefit of his opinion on a number of puzzling rock-structures.

Prof. E. J. Garwood has most kindly examined my slides of algal rocks, and has lent a number of his own slides for comparison. I have also had the advantage of going over the section with Prof. E. W. Skeats, Dr. Stanley Smith, and Dr. Edward Greenly. I wish to thank my laboratory assistant, Mr. J. E. Livingstone, for much willing help in regard to photographic and other work, and Mr. C. J. Bayzand, B.A., for 'white-lettering' Plates XI, XII, & XIII.

VI. Vertical Section of the Right Bank of the Avon (as shown in the main section).

	Thickness in ft.	in.	*Lithology.*	*Topographical details, etc.*
Km 83 ft.	about 8	0	Gap: section bricked up.	The section of Km described is that in the Lower Avonmouth line.
	13	6	Shale alternating with sandy mudstone and argillaceous limestone containing ostracods and calcareous algæ.	
	1	0	Compact limestone, with abundant ostracods and other fossils.	
	27	6	Shale, with subordinate bands of sandy mudstone and argillaceous limestone containing ostracods and calcareous algæ.	
	about 4	0	Limestone-band; lower part compact, crystalline, and thickly bedded, with crinoids, ostracods, and bryozoa; upper part marly and nodular.	First *Modiola* Phase.
	12	0	Thick shale, with a marly nodular band 5 to 6 feet from the top.	
	6	6	Thinly-bedded limestone and shale, the former very compact and black when unweathered; some bands crowded with ostracods and lamellibranchs.	
	1	0	Band of compact black limestone crowded with ostracods.	Crops out at the base of the cutting.
	9	6	Reddish shale and calcareous flaggy beds.	
α 25 ft.	4	0	Massive bed of red crinoidal limestone; the top has the character of pseudobreccia.	Bryozoa-Bed.
	3	3	Thinly-bedded reddish limestone and shale, with at the base a 6-inch band of yellow dolomite-mudstone.	
	17	9	Thickly-bedded, red, crinoidal limestone.	
K_1 70 ft.	3	6	Thinly-bedded sandy limestone.	
		6	Somewhat gritty and crinoidal limestone with teeth of fishes and coprolites.	Palate-Bed.
	2	6	Compact, somewhat laminated, sandy limestone with scattered phosphate-nodules.	
	19	6	Shale, with subordinate bands of highly fossiliferous limestone, generally crinoidal.	
	about 44	0	Section bricked up.	

	Thickness in ft. in.	Lithology.	Topographical details, etc.
K_2 285 ft.	about 150 0	Section obscured or bricked up.	
	about 35 0	Thinly-bedded limestone, with subordinate shale.	Poorly exposed in the railway-cutting.
	about 75 0	Shale, with subordinate limestone-bands.	Much overgrown, very poorly exposed in the railway-cutting.
	about 25 0	Thickly-bedded highly crinoidal and brachiopodal limestone, with thin shaly partings. Many fossils silicified.	Fairly well exposed in the northern part of Press's Quarry and in the adjacent railway-cutting.
β 20 ft.	about 20 0	Massive crinoidal and brachiopodal limestone. Many fossils silicified.	This band is shifted by the thrust-fault in Press's Quarry.
Z_1 134 ft.	28 0	Massive or thinly-bedded crinoidal and brachiopodal limestone partly dolomitized. Some silicification of the fossils in the lower part.	The prominent bedding-plane immediately south of Press's Quarry marks the top of the band. Near the top of this band is a layer showing patchy dolomitization.
	7 0	Massive, often highly fossiliferous, crinoidal limestone.	
	34 0	Thickly-bedded dolomite, becoming more fossiliferous near the top where a band of chert occurs.	The chert-band crops out above the prominent irregular bedding-plane at the northern end of Black Rock Quarry.
	65 0	Massive, highly fossiliferous, crinoidal and brachiopodal limestone. Matrix largely dolomitized.	The top is taken at the prominent bedding-plane by the path leading to the 'cave' (tunnel - opening) in Black Rock Quarry.
Z_2 182 ft.	165 0	Massive, highly fossiliferous, crinoidal limestone ('petit granit'). Matrix largely dolomitized.	Forms the main part of Black Rock Quarry. Lowest 25 feet much obscured by talus.
	17 0	'Fish-Beds,' massive, highly fossiliferous, crinoidal limestone ('petit granit') with teeth and spines of fishes. Matrix largely dolomitized.	The levels from which the fish-remains were obtained are three prominent bedding-planes respectively at the top, bottom, and middle of this band.
γ 60 ft.	60 0	Massive, highly fossiliferous, crinoidal limestone ('petit granit') with abundant Zaphrentids. Matrix largely dolomitized.	Well seen at the northern end of Black Rock Quarry and in the riverside exposure.
C_1 185 ft.	*Laminosa* Dolomite, about 95 0	Somewhat thickly bedded, thoroughly dolomitized, crinoidal limestone. At the top is the Suboolite-Bed, containing *Chonetes* and *Orthotetes*.	Lower beds seen at the southern end of Black Rock Quarry, the upper in the northern part of Gully Quarry and in the riverside exposure.
	Caninia Oolite, about 90 0	Massive, thickly-bedded, white oolite, with few fossils.	Well seen in Gully Quarry and by the road and river.
C_2 235 ft.	38 0	Thinly-bedded shales and dolomites, with a brown algal band at the top.	These beds, the '*Caninia* Dolomite' of Vaughan, are seen in the railway-cutting between the Gully Quarry and the Great Quarry.
	87 0	Thinly-bedded shales and dolomites, with a band of non-dolomitized oolite at the top.	
	110 0	Thinly-bedded shales and dolomites: the upper beds including calcite-mudstones and algal layers.	

		Thickness in ft. in.	Lithology.	Topographical details, etc.
S_1 160 ft.	$S_1(a)$ 92 ft.	47 0	Calcite-mudstones — thinly-bedded limestones with several algal layers, and at the base a band of *Diphyphyllum*.	
		14 0	China-stone, white and black, often laminated, dolomitized in places, and including two *Spongiostroma*-layers, the lowest *Seminula* Band and at the base the lowest band of *Seminula* Pisolite.	
		25 0	Somewhat thickly-bedded, considerably dolomitized limestone, with thick shaly partings and bands of *Lithostrotion martini*.	This band meets the back of the miniature rifle-range.
		6 0	Dolomitized limestone, with reddish fossiliferous shaly partings, passing up into china-stone with abundant *Seminula*.	The 'back slope' is near the top of this band.
	$S_1(b)$ 68 ft.	11 0	Partly dolomitized limestone, with shaly partings. About 8 feet from the base is a layer containing *Lithostrotion basaltiforme*.	Second *Modiola* Phase.
		14 0	Partly dolomitized limestone, the highest 2 feet of china-stone type, and at the top a shaly parting full of *Seminula*.	The shaly parting at the top of this band forms the 'front slope.'
		3 0	Partly dolomitized limestone, with abundant *Productus semireticulatus*, terminated by a shaly parting—the 'Trilobite-Bed.'	The 'Trilobite-Bed' contains pygidia of *Phillipsia* (rare), long *Productus* spines, and bryozoa.
		6 0	China-stone, with algal layers and pale dolomite.	
		18 0	Massive, much dolomitized limestone, with *Caninia bristolensis* and scattered *Lithostrotion* abundant in the lower part.	
		16 0	Massive, much dolomitized limestone, with large masses of *Lithostrotion martini*.	
S_2 447 ft.	$S_2(a)$ 124 ft.	100 0	Massive dolomitized limestone with abundant *Lithostrotion martini*, associated with white partly-dolomitized calcite-mudstone and a *Seminula*-Pisolite band.	
		20 0	Limestone partly dolomitized, with three chert-bands.	
		4 0	Dolomite.	The small cave seen high up on the quarry-side is in this layer.
	$S_2(b)$ 58 ft.	42 0	Fine oolite yielding many fossils (*Seminula* Oolite).	The bands constituting $S_2(b)$, the *Seminula* Oolite, form the lower part of the wall at the southern end of the Great Quarry.
		9 0	Limestones, mainly oolitic, showing desiccation-breccia-tion and sometimes *Seminula*-Pisolite structure.	
		7 0	Limestone, mainly oolitic, yielding abundantly *Chonetes papilionacea* in the upper part.	

	Thickness in ft.	in.	*Lithology.*	*Topographical details, etc.*
$S_2(c)$ 240 ft.	about 100	0	Massive grey limestone, partly dolomitized, with thin and widely spaced partings of red shale and abundant *Lithostrotion martini*.	The lower of the two divisions included in $S_2(c)$ forms the middle part of the wall at the southern end of the Great Quarry, the upper is ill-exposed above the wooded slope farther south. The highest beds are splendidly seen in the section as repeated by the fault and in the approach to the Suspension Bridge.
	about 140	0	Massive limestones, very ill-exposed in the main section on the right bank, but mainly foraminiferal. Some oolite in the lower part. Highest beds very fossiliferous, and showing well-marked bands of *Seminula* Pisolite.	Third *Modiola* Phase.
$S_2(d)$ 115 ft.	125	0	Massive limestone, occasionally oolitic, alternating with 'Concretionary' (algal) and *Seminula* Bands. Upper beds with shaly partings.	The 'Concretionary Beds' $S_2(d)$ are ill-exposed in the southern part of the wooded slope south of the Great Quarry.
D_1 375 ft.	about 135	0	Grey limestone, chiefly massive and thickly bedded, with foraminifera and corals; occasionally oolitic. Several prominent bands of pseudobreccia.	Seen in the northern part of the railway-cutting south of the New Zigzag level-crossing and in the roadside exposure north of Point Villa.
	about 40	0	More thinly-bedded limestone, often reddish, with rubbly and shaly bands and partings.	
	about 200	0	Limestone, in the main coarsely oolitic and massive, but including some non-oolitic bands associated (especially in the upper part) with massive red grits and thick shales. Some bands, both oolitic and non-oolitic, show pseudobrecciation.	Seen in the southern part of the railway-cutting south of the New Zigzag level-crossing, and in the lower part of the Bridge-Valley Road section.
D_2 184 ft.	3	0	Grit with quartz-pebbles.	Well-exposed by the roadside between the bottom of Bridge-Valley Road and Point Villa, in the upper portion of the Bridge-Valley Road section, and in part in Rownham Quarry.
	about 42	0	Grey limestone, chiefly compact but sometimes pseudobrecciated: corals and foraminifera abundant.	
	7	0	Coarse oolite.	
	22	0	Grey limestone as above, but with a narrow band of coarse oolite.	
	27	0	Oolitic limestone, thickly bedded, but with strong rubbly partings.	
	10	6	Grey limestone as above, upper part highly fossiliferous.	
	2	6	Coarse red oolite, top bed rubbly.	
	about 70	0	Red grits and shales ill-exposed, and extending to the Observatory-Hill Fault.	The base of the upper gritty and shaly series is seen in the road-section between the bottom of Bridge-Valley Road and Point Villa, and in the Bridge-Valley Road section. The highest beds are seen below the Observatory-Hill Fault.

[Total thickness = about 2543 feet.]

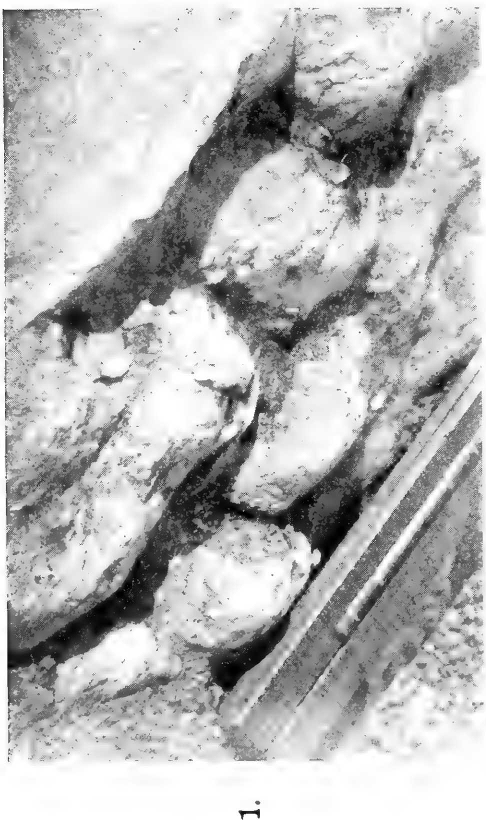
1.

2.

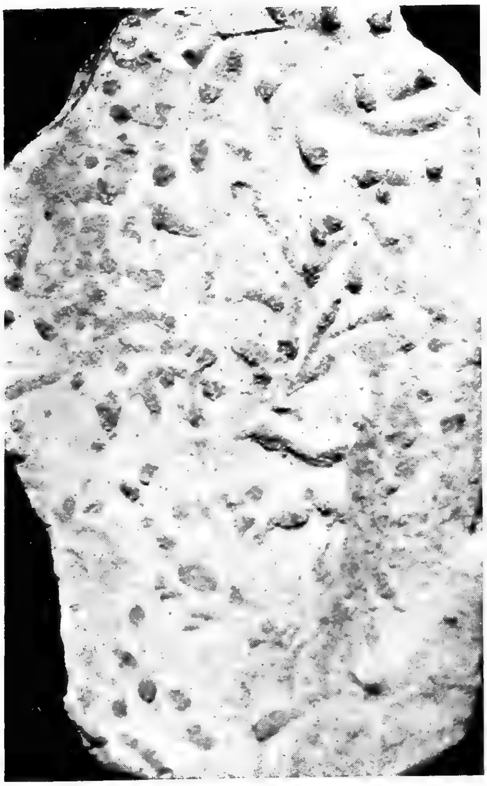
3.

4.

MITCHELDEANIA LIMESTONE, 'STICK-BED,' AND *SEMINULA* PISOLITE.



1.



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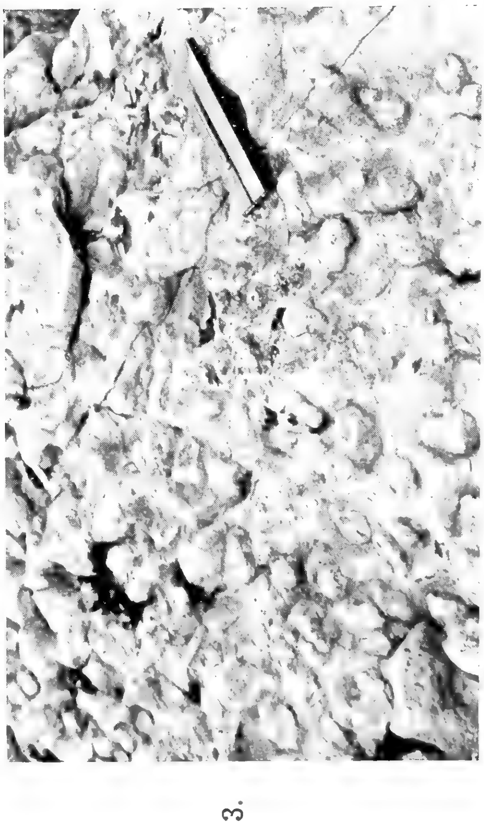

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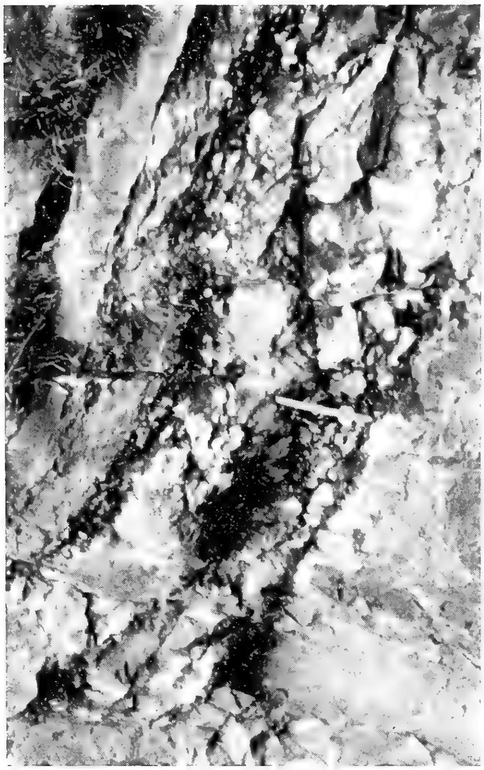
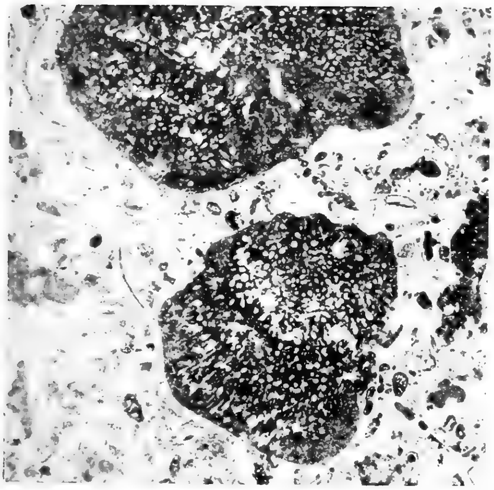


4.

SPONGIOSTROMA LIMESTONE, BORED CHINA-STONE, ALGAL LIMESTONE, AND 'RUBBLY LIMESTONE.'

1.



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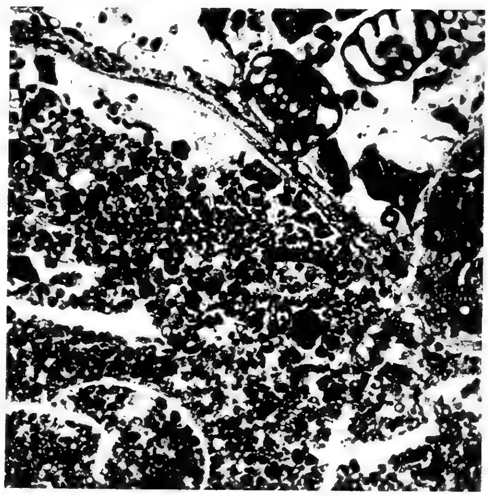
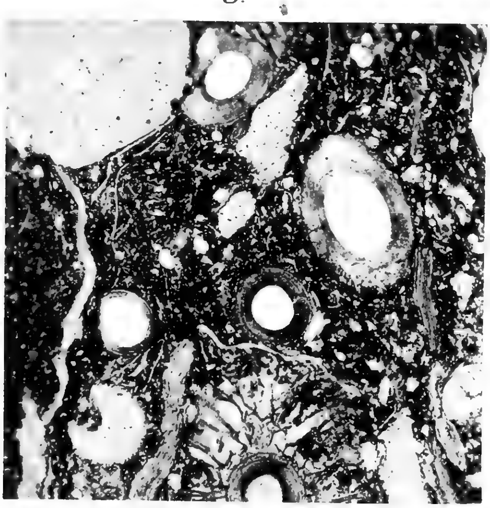


5.



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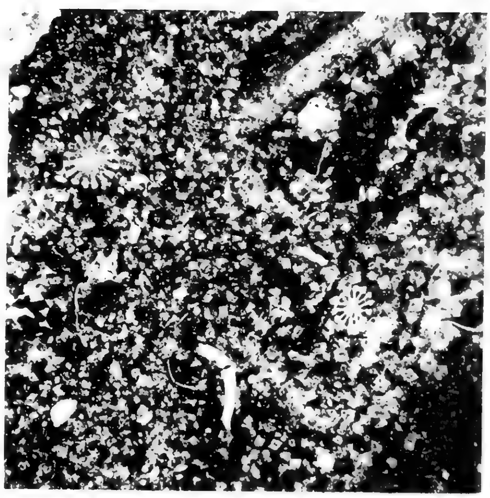
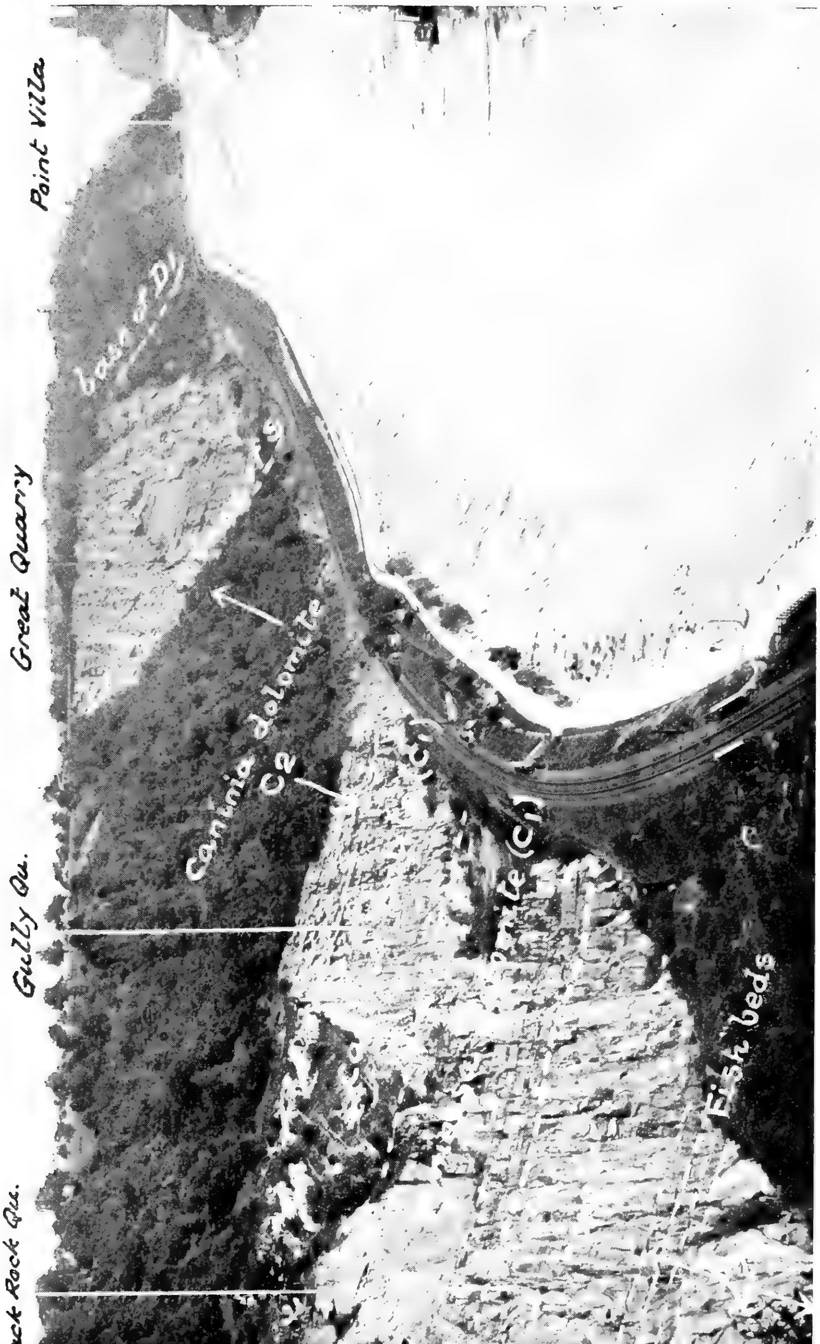


S.H.R. & J.E.L., Photomicro.

Bemrose, Collo, Derby.

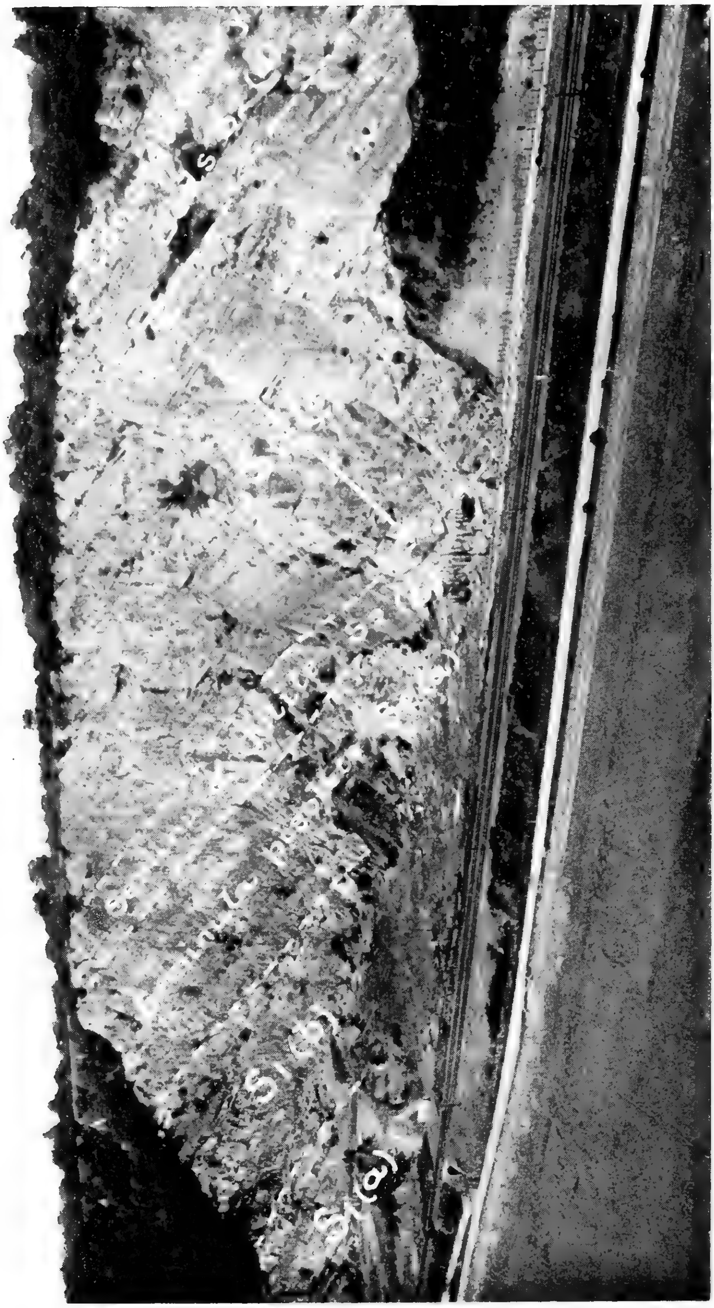
AVONIAN ROCKS OF THE AVON SECTION.



S. H. R. photo.

General View of the Avon Section, right bank, from near 'Sea-Walls.'

Quart. Journ. Geol. Soc. Vol. LXXVII, Pl. XII.



S.H.R. photo.

THE GREAT QUARRY, AVON SECTION, RIGHT BANK.

S. H. R. photo.

NORTHERN END OF THE GREAT QUARRY, AVON SECTION, RIGHT BANK.

S. H. R. photo.

Caninia Dolomite (C_2), resting upon *Caninia* Oolite (C_1), Quarry 3, Avon Section, left bank.

EXPLANATION OF PLATES VIII–XIV.

Plate VIII.

Fig. 1. *Mitcheldeania* Limestone (Km) (A 182). Riverside exposure, northern end of section, left bank. × 4/5. (See p. 216.)

2. Brecciated *Mitcheldeania* Limestone (Km) (A 181). Riverside exposure, northern end of section, left bank. × 4/5. (See p. 216.)
3. 'Stick-Bed' (block not in place) (S_1). Northern end of Great Quarry (scale given by 6-inch measure). (See p. 227.)
4. *Seminula* Pisolite, $S_2(a)$. Great Quarry. × about 1/2. (See p. 228.)

Plate IX.

Fig. 1. *Spongiostroma* limestone (S_1). Northern end of the Great Quarry. × 2/5. (Scale given by 6-inch measure.) (See p. 226.)

2. China-stone with ? borings (S_1). Northern end of the Great Quarry. × 3/4. (See p. 226.)
3. Algal limestone, Concretionary Beds, $S_2(d)$. Observatory Hill, Clifton. (Scale given by 6-inch measure.) (See p. 230.)
4. 'Rubbly Limestone,' showing its discontinuous character (D_2). By road, south of Point Villa. (Scale given by foot-rule.) (See p. 234.)

Plate X.

[All figures in this plate are magnified about 15 diameters.]

Fig. 1. Algal Limestone (Km). Lower Avonmouth railway-section. Patches of *Mitcheldeania* rounded by solution following penecontemporaneous brecciation. (See p. 216.)

2. Limestone with *Solenopora* (K). Avon Section, right bank. (Prof. E. J. Garwood's collection.) (See p. 216.)
3. Gritty limestone, with rolled shell-fragments (Km). (A 14.) Lower Avonmouth railway-section. (See p. 216.)
4. Calcite-mudstone, with ostracods, foraminifera, and rounded patches (S_1 base). (A 91.) Northern end of the Great Quarry. (See p. 226.)
5. Limestone with spines of *Productus* (S_1). (A 104 *a*.) Northern end of Great Quarry. Several sections of crinoids are also seen, and one of the *Productus* spines has a bryozoan(?) growth round it. (See p. 227.)
6. Partly dolomitized limestone with spines of ? *Palechinus* (S_2 base). (A 111.) Great Quarry. (See p. 227.)

Plate XI.

General view of the Avon Section, right bank, from near 'Sea-Walls.'

Plate XII.

The Great Quarry, Avon Section, right bank.

Plate XIII.

Northern end of the Great Quarry, Avon Section, right bank.

Plate XIV.

Caninia Dolomite (C_2) resting upon *Caninia* Oolite (C_1), Quarry 3, Avon Section, left bank.

Discussion.

Prof. E. J. Garwood congratulated the Author on the interesting results which he had obtained from a detailed study of the petrological characters of the rocks of the Avon gorge, and expressed his admiration of the beautiful photographs of rock-structures thrown on the screen. He was especially interested to hear of the numerous horizons at which calcareous algæ had been found, and the important part that they had played as rock-builders, together with the problematic form *Spongiostroma*, which he had found to have a widespread distribution in the Lower Carboniferous rocks of Britain and Belgium, associated with algal remains. He would like to ask the Author whether he had been able to differentiate between different species of *Mitcheldeania*, and whether these species were characteristic of different horizons, as at Mitcheldean and in North Cumberland, where *M. nicholsoni* occurred in K and *M. gregaria* in C_2 or the top of C_1. Also whether the interesting little bodies characteristic of the china-stones, usually designated *Calcispheræ*, were sufficiently well preserved in the Avon rocks to be capable of specific identification, and whether they threw any new light on the true nature of these organisms. He was interested in the Author's description of the occurrence of 'spotted beds,' which recalled those described by the speaker from Great Rundle Beck in the Pennines; quartz-grains were conspicuous in the matrix of these beds, though almost absent from the spots.

Prof. O. T. Jones remarked that they could not have too many papers on the conditions of deposition of sedimentary rocks—a subject which was still far from being well understood; but it was not easy to present the necessarily detailed observations in an interesting manner. The Author, with the aid of his fine series of lantern-slides, had succeeded admirably. It was of considerable interest to note that the Bristol area showed such close resemblance to the Gower area, so ably described by Dixon & Vaughan, and that all observations on the Carboniferous Limestone Series agree in indicating that the series from top to bottom was formed under relatively shallow-water conditions. Not many years ago, following the descriptions of deep-sea deposits by the *Challenger* Expedition, the pure limestones of the South of Britain were regarded as deep-sea deposits, of which the Lower Carboniferous rocks of the North of England were the shallow-water representatives. The Coddon Hill Shales with their radiolarian cherts were even supposed to represent a still-deeper water development. The fallacy of these views in regard to the limestone facies had now been amply demonstrated; but the lesson, so far as the North Devon rocks were concerned, had not been driven home as thoroughly as it should have been. He also asked the Author whether it was now proposed to draw the line between the Upper and the Lower Avonian at the top of the *Caninia* Oolite, where

a sharp change of conditions seemed to be indicated in some of the Author's slides.

The AUTHOR thanked the previous speakers for their kind reference to his paper. In reply to Prof. Garwood, he said that he had not paid attention to specific differences in either the *Mitcheldeania* or the *Calcisphera* that he had met with. With regard to a question concerning basin-shaped hollows in the S_2 limestone, he replied that hollows, perhaps of the kind suggested, occurred in the pseudobreccias of D_1 at Mells, but he had not seen anything of the kind in the S beds. To Prof. Jones he said that he had only been concerned with questions of lithology, but that he agreed with those who had specially investigated the Carboniferous Limestone in drawing the line between the Upper and the Lower Avonian of the South-Western Province at the top of C_1: although in the Avon Section there was no unconformity or even non-sequence at this level, there was a marked change in lithology.

11. Geological Sections *through the* Andes *of* Peru *and* Bolivia: III—*From the* Port *of* Callao *to the* River Perene. By James Archibald Douglas, M.A., B.Sc., F.G.S. (Read April 20th, 1921.)

[Plates XV–XX.]

Contents.

I. Introduction.

This paper deals with the geological structure of the Andes of Central Peru, as represented by a horizontal section drawn from the island of San Lorenzo off the Pacific coast at Callao to the River Perene, a tributary of the Apurimac, one of the headwaters of the Ucayali. It is a third contribution to a series of papers written as the result of a two years' expedition to South America (1910–12) undertaken on behalf of the late Mr. W. E. Balston, F.G.S.

The district traversed is one of the best-known and most populous in Peru, for through it passes the northern Transandine route from Lima, the capital of the country, to the port of Iquitos on the Amazon, whence steamers sail direct to Europe.

The first half of the section follows the line of the central railway of Peru. This is the well-known Oroya line, famous not only as the highest railway in the world, but also as a wonderful feat of engineering, rising as it does to an altitude of over 15,000 feet in a course of 100 miles. The line ascends the steep-sided valley of the Rimac by means of a series of sinuous curves and zigzag 'switchbacks,' cut for the greater part in the face of the solid rock. After passing through no fewer than 65 tunnels it reaches the summit of the watershed between the Atlantic and the Pacific river-systems at Ticlio, 15,665 feet above sea-level, and thence descending to 12,000 feet terminates at the junction of Oroya. From Ticlio a branch-line leads to the important mining centre of Morococha, situated in a valley remarkable for the perfection of its glacial topography. At Oroya it makes connexion with lines from the celebrated copper-mines of Cerro de Pasco and from the agricultural districts of Jauja and Huancayo farther south. In addition, it furnishes an outlet for the coffee growing region of the interior.

Leaving the railway at Oroya, the section is continued eastwards

along the route to Chanchomayo. After the longitudinal valley of the Mantaro has been crossed, a second and subsidiary watershed is met with at 14,000 feet, from which a steep descent is made down the Tarma valley. About 25 miles beyond the village of that name, at the Tambo of Huacapistana, are encountered the first signs of luxuriant vegetation, denoting the western limit of the Montaña district. The scenery at this point is very similar to that of a typical valley in the Swiss Alps; but with a further descent the temperature rapidly increases, and the tropical character of the flora becomes pronounced.

At San Ramon the Tarma River is joined by the Tulomayo to form the Chanchomayo, and this in turn unites with the Paucartambo to form the River Perene, one of the headwaters of the Amazonian system. This point, which forms the eastern limit of the section, although distant more than 2000 miles from the Atlantic coast, is only 1145 feet above sea-level.

The earliest-recorded observations on the geology of the Lima district were those made by Charles Darwin during the voyage of the 'Beagle' in 1835, which dealt chiefly with the evidence as to recent uplift afforded by the kitchen-middens of the island of San Lorenzo. Little attention, however, seems to have been paid to the structure of the mountainous region of the mainland until the beginning of the present century, when the first definite account of its geological features, illustrated by a section across the Cordillera, was published by Prof. Gustav Steinmann as the result of a journey made in 1904 from Lima to the Chanchomayo River.[1] Of late years our knowledge of the district has been further enriched by the writings of Prof. Carlos I. Lisson, of Lima, who has made a detailed study of the country in the immediate neighbourhood of the capital.

In view of the fact that my route across this part of the Andes was identical with that taken by Steinmann, although continued some miles farther towards the east, anything more than a summarized account of my observations does not appear to be necessary, except in so far as they afford additional evidence for the facts already recorded. In many cases, however, the views of that author are not in accordance with mine, and I have therefore been led to give an independent interpretation of the section, in order to illustrate the points upon which we appear to differ. It is only fair to add that more than once I have been able to strengthen or confirm my views on obscure facts by reference at a later date to his paper mentioned above.

A preliminary study of the physical features of this part of the country shows that they differ markedly in character from those prevailing in the South of Peru and the North of Chile, as described by me in former papers of this series. Four principal topographic

[1] See Bibliography, p. 282, § IV, No. 46.

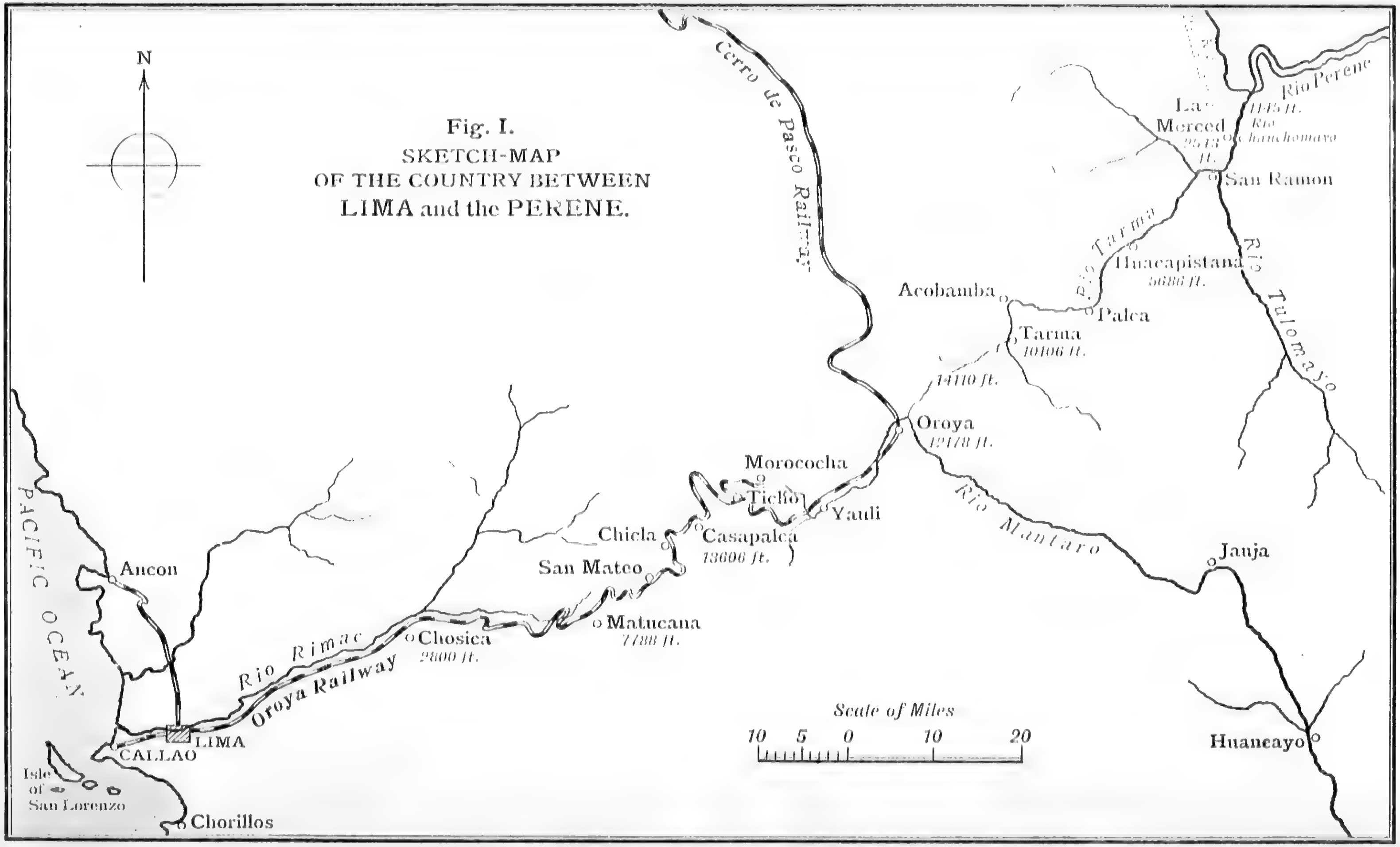


Fig. I.
SKETCH-MAP
OF THE COUNTRY BETWEEN
LIMA and the PERENE.

zones were there recognized, which, for the purposes of comparison, may be briefly restated as comprising

(1) A coastal desert fringing the Pacific Ocean, and bounded on the west by fragmentary remains of an ancient coastal Cordillera formed of gneisses and plutonic rocks, probably of Archæan age.
(2) A giant range of recent volcanic cones, capping the Mesozoic rocks of the Western Cordillera, and forming its outstanding topographic feature.
(3) An inter-Andean high-level region, comprising the Altaplanicie of Bolivia and the area occupied by Lake Titicaca with the longitudinal valleys of the Desaguadero and the Vilcamayo Rivers; a region formed chiefly of the later Palæozoic and transgressive Mesozoic rocks.
(4) An Eastern Cordillera (the Cordillera Real of Bolivia), formed of granite and early Palæozoic rocks, and bounded on the east by a sharp descent to the forested region of the Montaña.

From the description given in the following pages, it will be seen that these salient features which find expression in the south no longer prevail in Central Peru. The mountainous region here extends almost to the shores of the Pacific, to the exclusion of the coastal desert.

The zone of recent volcanoes is entirely wanting, and Mesozoic sediments with their intrusive batholithic core here play the chief part in determining the configuration of the Cordillera, outcrops of plutonic rock being met with in some cases almost at the summit of the range.

The inter-Andean region is represented in the latitude of Lima by the narrow longitudinal valley of the Mantaro, here, not far from its source, forming but an insignificant feature of the topography; while the low divide which bounds it on the east can in no way be regarded as constituting an eastern Cordillera. Farther north, the longitudinal depressions of the Marañon and Huallaga rivers once more tend to divide the range into a series of parallel chains; but along the line of section here described they unite to form a single Cordillera, aptly described by Raimondi as a 'mountain-knot.'

It is important to lay stress upon this fact, for Eduard Suess [1] in his summary of the structure of the Andes refers to the range east of Lima as 'the first lofty chain of the Andes'—a statement that suggests the presence of other chains parallel to it on the east, which in reality do not exist.

II. Geological Description of the Section from Callao to the River Perene.

Before commencing the description of the geological structure of the country traversed by the present section, I think it necessary to refer once more to the crystalline gneisses and associated igneous rocks, which indicate the existence of an ancient coastal Cordillera

[1] 'The Face of the Earth' Engl. transl. vol. iv (1909) pt. 5, ch. xiii, p. 468.

in the South of Peru, represented at the present day by isolated fragments bounding the shores of the Pacific. Rocks of this nature are said by Prof. Steinmann to extend as far north as Pisco; but, as the result of observations made during a visit to that locality, I am led to question the accuracy of such a statement. In the peninsula of Paracas, a few miles south of the port, the rocks on the coast were found to consist of coal-bearing quartzites of Palæozoic age, yielding numerous plant-remains. These beds are overlain unconformably by marine Tertiary deposits, pierced by later igneous intrusions; but I could find no trace of the existence of ancient igneous rocks or crystalline gneisses such as occur farther south.

The plutonic rocks met with in the neighbourhood of Ica belong to the granodioritic series of the main Cordillera, and are not to be confused with the granitic rocks of the coastal series. The presence of these Carboniferous deposits at Paracas is of considerable interest, for they furnish the only known occurrence of fossiliferous Palæozoic strata on the Pacific coast of Peru, and, moreover, disprove the statement of David Forbes [1] that there is 'no example of the occurrence of Carboniferous beds anywhere along the coast of the Pacific in South America.'

An accurate determination of the age of the flora is, therefore, of great importance, the more so as Prof. A. C. Seward, who has very kindly offered to study the specimens which I collected, has pointed out to me that a list of species previously published by F. Fuchs [2] contains both Wealden and Carboniferous forms. The result of Prof. Seward's research will doubtless show that the determinations of that author were erroneous.

In the neighbourhood of Lima the zone of Mesozoic rocks extends to the coast, and any continuation of the coastal Cordillera of the south lies submerged beneath the waters of the Pacific. That this fact has not always been hitherto fully recognized is clear from the account given by Eduard Suess [3] of this area, of which he remarks

'we may start from Lima and proceed up the valley of the Rimac . . . (and) we shall first come upon the broad, often gold-producing granite-ridges of the Coast Cordillera.'

As will be shown later, the 'Andes granite' of the Lima district is of post-Cretaceous age, and is totally distinct from the ancient granite of the coast in Southern Peru. Nowhere in the sections previously described does the Mesozoic zone contribute so largely to the formation of the lofty Cordillera as it does along the line of the section now described, where it can be followed more or less continuously from the Pacific coast to the eastern slopes of the range.

[1] Q. J. G. S. vol. xvii (1861) p. 51.

[2] 'Nota sobre el Terreno Carbonifero de Paracas' Bol. de Minas, 1900, Lima (Peru).

[3] 'The Face of the Earth' Engl. transl. vol. i (1904) pt. 2, ch. ix, p. 528.

Three main types of deposit can be recognized, succeeding one another in the following order from west to east :—

(1) A shallow-water facies, consisting chiefly of sandstones and shales ; the frequent presence of plant-remains in the latter indicates the close proximity of land during their deposition.
(2) A volcanic facies of pyroclastic origin, comprising contemporaneous tuffs and agglomerates, corresponding to Forbes's 'porphyritic conglomerate' of Bolivia.
(3) A calcareous facies, consisting of richly-fossiliferous limestones and marls.

The section described in the following pages begins at the Island of San Lorenzo, which lies some 4 miles off the mainland, and is separated from the promontory of La Punta and its continuation in the shallow bank of Camotal by the narrow straits of Boqueron.

Here, and in the immediate neighbourhood of Lima, the first or shallow-water type of Mesozoic deposit attains its maximum development. A detailed account of the succession has already been given by Prof. C. I. Lisson,[1] to whose admirable work reference may be made for a complete description of the district.

The rocks are well exposed along the shores of the island, where they are seen to consist of an alternating sequence of grey, green, and red shales, olive-green quartzites and sandstones, with occasional bands of impure limestone. The beds have an almost constant dip of about 20° south-south-westwards, and form the western limb of a large anticlinal flexure, the eastern limb of which is encountered on the mainland.

A well-defined raised beach, about 10 feet above the present high-water mark, is preserved along the eastern shore of the island.

Numerous fossils have been recorded from San Lorenzo : the commonest is a species of *Trigonia* (*T. lorentii* Dana), and specimens of it were found in some abundance during our short visit to the island, just above beach-level along the west side of the first bay north of the sanitary station, the fossiliferous bed being a reddish-green calcareous grit.

This is overlain by grey shales and sandstone in which large fragments of fossil wood occur. Badly-preserved fish-teeth and a specimen of *Hoplites* (cf. *Thurmannia thurmanni*, Pictet & Campiche) were also collected at this locality.

In the rocks of the Caleta del Paraiso plant-remains are plentiful, and from material obtained by Prof. G. Steinmann, Dr. R. Neumann has assigned a Wealden age to this flora.[2]

If the beds exposed on the Island of San Lorenzo be projected along their strike towards the south-east, they are seen to crop out on the coast of the mainland on the south side of Chorillos Bay, where, by the aid of Prof. Lisson's memoir, it was found easy to follow the details of the succession and discover the fossiliferous

[1] 'Contribucion à la Geologia de Lima & sus Alrededores' 1907.
[2] 'Beiträge zur Kenntnis der Kreideformation in Mittel-Peru' Neues Jahrb. Beilage-Band xxiv (1907) pp. 69–132.

horizons. The beds are best examined in the spur of Salto del Fraile (the Friar's Leap) and in the cliffs on the south side of the Caleta de la Herradura, where they are again seen to have a constant dip south-south-westwards corresponding to that observed on San Lorenzo.

Near the base of the succession occurs a series of coarsely-bedded quartzites crowded with the casts of U-shaped annelid-tubes (*Glossifungites habichi* Lisson).[1] These are frequently arranged in well-defined layers, each successive colony doubtless representing a pause in the deposition of the bed, possibly due to seasonal variation. In other cases, where sedimentation appears to have been more continuous, individual tubes are seen to have undergone a periodical displacement upwards, resulting in a repetition of the U's in a vertical series. The whole formation is suggestive of deposition in shallow water between tide-levels, such as might well occur on a sandy beach, crowded with worm-casts, at the present day.

In addition to these annelid-tubes, other casts occur, the origin of which is less certain. One type in particular, especially abundant on the lower surface of a quartzite-band at its junction with an underlying black shale, consisted of numerous freely-intersecting tubes, about 1 inch in diameter and more or less circular in cross-section, the interior of which was made up of countless ramifying tubules of almost microscopic dimensions.

The quartzites of Salto del Fraile are overlain by a succession of black shales, mottled quartzites, and impure limestones forming the Morro Solar, from which Prof. Lisson has obtained a rich fauna including several species of ammonites, such as *Hoplites (Acanthodiscus) raimondii* Gabb, *H. (A.) pflueckeri* Lisson, and *H. lorensis* Lisson.

The beds are pierced in many places by a fine-grained basic porphyrite, occurring in the form both of vertical dykes and of intrusive sills. Owing to the jointing of the igneous rock, however, these have offered less resistance to erosion than the quartzites, and, where fully exposed to the action of the sea, their former extension is often shown merely by open fissures.

Relying chiefly on the evidence afforded by the above-mentioned ammonites and the fossil flora of the Caleta del Paraiso, Lisson and Steinmann regard these beds of Salto del Fraile and San Lorenzo as being of Neocomian age; and in support of this view it may be noted that the sub-genus *Acanthodiscus* makes its appearance in Europe in Lower Valanginian times and Pictet's species *A. malbosi*, which seems to bear the closest resemblance to *A. pflueckeri* Lisson, is one of the earliest-known forms.

A study of the Trigonias, moreover, throws further light on this question (see palæontological note). Of these, *Trigonia lorentii* Dana is of chief importance, its interest lying in its similarity to

[1] See also H. Douvillé, 'Perforations d'Annélides' Bull. Soc. Géol. France, ser. 4, vol. vii (1907) pp. 361–70 & pl. xii.

members of the same group found in the Oomia Beds of Cutch and in the Uitenhage Beds of South Africa (now generally regarded as Neocomian).[1] This is shown by the possession of two series of obliquely-inclined ribs which meet along a line joining the umbo of the shell with a point on its ventral margin, to form an angular or *V-scripta* type of ornament. Since the material at my disposal is not sufficiently good to indicate the early stages of growth, it is impossible to say whether this is a homogenetic character shared alike by the South American, Indian, and South African forms, or whether it has been attained by convergence of heterogenetic lines of development.

Such being the case, in the absence of associated forms common to the three sets of deposits, it would be unsafe to regard these shells as furnishing conclusive proof of contemporaneity. If taken in conjunction with the presence of *Acanthodiscus*, however, the peculiar nature of their ornament is not without significance.

Palæontological Note.

TRIGONIA LORENTII Dana. (Pl. XV, fig. 7.)

In order to illustrate the structural differences which exist between this and the closely-allied forms from South Africa and India the following note may be added to the description of the species given by Prof. C. I. Lisson ('Geologia de Lima, &c.' 1907, p. 32 & pl. iii, figs. 2–3).

From *Trigonia vau* Sharpe (F. L. Kitchin, Ann. S. Afr. Mus. vol. vii, 1913, p. 110 & pl. vi, figs. 1–3, 'Invertebrate Fauna & Palæontological Relations of the Uitenhage Series') *T. lorentii* is distinguished by its triangular shape and absence of posterior elongation. In the former species the number of ribs in the anterior and the posterior series is approximately equal, whereas in the Peruvian form those in the anterior series are twice as numerous. In *T. lorentii*, moreover, the ribs are strongly and completely developed in the adult shell, while in Sharpe's species the anterior series tend to die out near the frontal margin before the individual has attained more than half its growth.

From *Trigonia stowi* Kitchin (*ibid.* p. 115 & pl. vi, figs. 4–5, pl. vii, fig. 1) it differs in the possession of a rounded anterior margin as opposed to the angular shape of that species, in the regularity and greater obliquity of the V's, and in the absence of a siphonal gape.

From *Trigonia dubia* Kitchin ('Palæontologia Indica' ser. ix, vol. iii, pt. 2, 1903, p. 67 & pl. vii, figs. 3–5) it differs in general outline and degree of inflation (this being considerably less in the Peruvian form), while the ribs are narrower and more angular.

From *Trigonia V-scripta* Kitchin (*ibid.* p. 70 & pl. vii, figs. 6–8, pl. viii, figs. 1–3) it is easily distinguished by the regularity of its ribbing and the obliquity of the V's.

Individual shells in my collection are seen to vary considerably in the details of their ribbing; but, without examining a large number of specimens, it is impossible to say whether they are of sufficient importance to rank as separate species.

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[1] W. M. Gabb, in describing a collection of fossils made by Dr. Antonio Raimondi in Peru, says, in speaking of *Trigonia lorentii*, 'from its type, evidently Jurassic'; and Raimondi himself was of the opinion that the beds of Salto del Fraile were of Liassic age. Journ. Acad. Nat. Sci. Philad. ser. 2, vol. viii (1874–81) pp. 288–89.

Three distinct forms may be noted:

Form *a*. Anterior ribs very regular, straight or slightly concave towards the umbo, forming an angle of 45° with those of the posterior series, and cutting the growth-lines at an angle of about 30°.

Form *b*. Anterior ribs almost parallel to the growth-lines, slightly concave towards the umbo near the anterior margin; but midway between the margin and the angle of the V this gives place to a distinct convex curvature. Angle of V's = about 80°.

Form *c*. The convex curvature noted above becomes a distinct re-entrant angle, separating a series of obtuse anterior V's from an acute posterior series.

The above-mentioned beds of the Island of San Lorenzo, Salto del Fraile, and the Morro Solar form part of the western limb of a large anticlinal flexure, and the corresponding members of the eastern limb are met with in the country north and north-west of Lima, where exposures are numerous and fossils are common at more than one locality.

The axis of the anticline appears to run in an approximately north-and-south direction midway between Lima and Callao, for black shales and quartzites, much veined with calcite, are seen dipping 35° east-north-eastwards immediately north of the city and again at the Cerro Palao; while at Puente Inga, west of this line, and again farther north at Ancon, the beds dip in the opposite direction.

At the last-named locality the rocks consist of unfossiliferous quartzites, similar in character to those of Salto del Fraile, with a thick interbedded sheet of andesitic lava. The latter seems to be of contemporaneous origin and not to partake of the nature of an intrusive sill, for it is associated with beds of porphyritic breccia containing angular fragments of a similar rock. It presents the appearance of being made up of a number of large spheroidal masses, but it is difficult to say whether this is true pillow-structure or merely a phenomenon due to weathering along joint-planes. Similar rocks can be followed along the coast towards Huacho.

One of the most important fossiliferous localities is that known as Puente Inga, a bridge over the Rio Chillon, some 10 miles north-west of Lima. The rock consists here of a peculiar and very characteristic pale-green and grey laminated clay, with a soft unctuous feel. Fossils are abundant, ammonites being the chief forms; but these as a rule are much crushed and badly-preserved, often merely in the form of casts.

If we judge from the westward dip of the beds and their position near the core of the anticline, it would appear that these belong to the oldest formation in the district and underlie the deposits of San Lorenzo. It must be remembered, however, that a large tract of the intervening country lies below sea-level, wherefore the actual continuity of the sequence cannot be proved; and, although no counter-dips are to be observed between this point and the coast, a marked deflection of the strike is noticed when the beds are again encountered on the island.

In the absence of any proved break, Prof. Lisson accounts for this fact by assuming that the axis of the anticline turns in a south-easterly direction when traced southwards across the Rimac. That author further recognizes two distinct faunas: an upper (Valanginian) represented by the deposits of San Lorenzo–Morrc Solar, and a lower represented by those of Puente Inga and Cerro Palao, the last-named being overlain on the east by the beds of Piñonate, a locality close to Lima, containing a Wealden flora. This lower fauna he regards as being of Portlandian age,[1] a conclusion to which he appears to have been led by reasoning mainly on stratigraphical grounds; for, in an earlier publication, he definitely assigns the beds of Puente Inga to the Lower Cretaceous.[2]

This, however, is not a matter of great importance, if we make comparison with other known deposits of transitional character such as that described by C. Burckhardt from Mexico,[3] but the following analysis [4] of a list of forms cited as coming from Puente Inga, many of which are represented in my own collection from this locality, tends to show that even higher horizons than the Valanginian are present, and therefore it is by no means certain that these beds are lower than those of San Lorenzo.

The Wealden flora of Piñonate and the Caleta del Paraiso cannot, in my opinion, be taken as indicating a definite horizon from which to judge the relative position of the marine deposits, for similar terrestrial conditions may have persisted throughout Lower Cretaceous times, and the same flora might recur anywhere in the succession.

HOPLITES (BERRIASELLA) *cf.* CALISTO A. d'Orbigny=BERRIASELLA CALISTO (A. d'Orbigny).

Specimens in my collection agree closely with the syntypes of A. d'Orbigny's species preserved in the Natural History Museum of Paris,[5] and with others figured by A. Toucas.[6] This species, according to W. Kilian,[7] characterizes the Upper Tithonian or Berriasien Inférieur.

An allied form, characterized by finer ribbing, appears to be more closely related to *Berriasella tenuicostata* Burckhardt,[8] a species found in beds transitional between Jurassic and Cretaceous.

HOPLITES (NEOCOMITES) LIMENSIS Lisson, a form originally figured and described as *Cosmoceras limense* Lisson.[9]

I am unable to separate this species from *Berriasella calisto* (A. d'Orbigny).

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[1] 'Edad de los Fosiles Peruanos & Distribucion de sus Depositos en la Republica' Lima, 1913, pp. 24–25.

[2] 'Geologia de Lima & sus Alrededores' 1907, p. 64.

[3] 'Faunes Jurassiques & Crétaciques de San Pedro del Gallo' Bol. Inst. Geol. Mexico (1912) No. 29.

[4] Based largely on the authority of V. Pâquier & W. Kilian, 'Lethæa Geognostica' pt. 2, vol. iii, Kreide I, 1907.

[5] See Palæontologia Universalis, ser. 3, fasc. iii (1911) pl. ccxxvi.

[6] 'Étude de la Faune des Couches Tithoniques de l'Ardèche' Bull. Soc. Géol. France, ser. 3, vol. xviii (1890) p. 600 & pl. xvii, fig. 3.

[7] 'Lethæa Geognostica' p. 183.

[8] Bol. Inst. Geol. Mex. 29 (1912) p. 161 & pl. xxxix, fig. 3.

[9] 'Geologia de Lima, &c.' 1907, p. 56 & pl. x, fig. 1.

The well-preserved oral lappet is similar in character to that of *Hoplites hyatti* Stanton, from the Knoxville Beds of California.[1]

HOPLITES (ACANTHODISCUS) *cf.* RAIMONDI (Gabb)=AMMONITES RAIMONDIANUS Gabb.

This sub-genus makes its appearance in Europe in Lower Valanginian times.

HOPLITES (NEOCOMITES) *cf.* THURMANNI Pictet & Campiche = THURMANNIA THURMANNI (Pictet & Campiche).

This species is very abundant in the Mid-Valanginian of Europe (zone of *Kilianella roubaudiana* (A. d'Orbigny),[2] and continues into the Hauterivian.

HOPLITES (LEOPOLDIA) *cf.* CASTELLANENSIS A. d'Orbigny.

This species is taken in Europe as the lowest sub-zonal index of the Lower Hauterivian.

HOPLITES (LEOPOLDIA) PERUANUS Lisson, originally described as *Hoplites leopoldi* D'Orbigny var. *peruana* Lisson.

A. d'Orbigny's species occurs in the Lower Hauterivian of Europe, sub-zone of *Hoplites castellanensis* D'Orbigny.

HOLCOSTEPHANUS (SPITICERAS) *cf.* NEGRELI Matheron.

A Lower Valanginian form occurring in the zone of *Hoplites* (*Thurmannia*) *boissieri* Pictet. According to Burckhardt, it is also found in the *Spiticeras*-Beds of Mexico (Lower Valanginian).

SCHLŒNBACHIA (NICKLESIA) *cf.* CULTRATA A. d'Orbigny.

A Lower Hauterivian form, sub-zone of *Leopoldia castellanensis* (D'Orbigny).

ANCYLOCERAS *cf.* SABAUDIANUM Pictet & Loriol=CRIOCERAS (LEPTOCERAS) SABAUDIANUM (Pictet & Loriol).

A Barremian species.

AUCELLA sp. Originally figured and described as a *Synclonema* (*Syncyclonema*).[3]

From the known distribution of the genus *Aucella*, its occurrence here would not be expected.

Having given a brief view of the development of the shallow-water Lower Cretaceous deposits of the coastal region, I may now proceed to a discussion of the plutonic rocks which, as seen in the section, follow them on the east.

In this district we once more traverse the great line of batholithic intrusion which forms the core of the Andes throughout Peru. Its occurrence has already been noticed in the extreme south of the country, in the valley of the Llutah near Arica; thence it was traced northwards, past Tacna and Moquegua, to the Cerros de la Caldera near Arequipa. During the course of the expedition it was also met with at Ica, and again in the district now described; while still farther north it was proved to occur in the region of Trujillo, where it constitutes the sea-cliffs at Salaverry, and inland from Pacasmayo on the route to Cajamarca.

[1] Bull. U.S. Geol. Surv. 133 (1895) pl. xvi, fig. 2.
[2] W. Kilian, 'Lethæa Geognostica' p. 193.
[3] C. I. Lisson, 'Geologia de Lima, &c.' 1907, p. 31 & pl. iii, fig. 4.

It is thus seen to form an almost continuous line for more than 750 miles, and throughout the whole of this extent the rocks of which it is composed were found to possess a uniform petrological character, consisting for the most part of coarse-grained acid granodiorites, frequently associated with more basic diorites, and in places showing a transition to the adamellite-monzonite group.

Rocks of alkaline facies are totally lacking, and thus a marked distinction can be drawn between these calcic rocks of the central core and, on the one hand, the true granites of the coastal Cordillera, on the other, the granites and syenites of the eastern slopes. This distinction, moreover, is not only one of petrological character, but also probably one of geological age.

In a former paper evidence was put forward to show that the batholithic intrusion took place, in part at least, in pre-Cretaceous times; but in the district here described it is clearly of post-Cretaceous date, and doubtless accompanied the great Tertiary folding of the Andes.

The relationship between the sedimentary and the plutonic rocks is well displayed in the Cerro San Cristobal, a hill close to the northern outskirts of Lima. The granodiorite is here seen to cut across the bedding-planes of steeply-dipping Cretaceous strata, which furnish abundant evidence of having been metamorphosed along the margin of contact. From this point it is more or less continuously exposed along the valley of the Rimac nearly as far as Matucana, and, although not met with again along our actual line of section, it crops out once more near the summit of the range in the Morococha Valley.

Throughout this lateral extent it does not consist of one type of rock alone, but on the contrary suggests two distinct phases of instrusion,[1] the first represented by a diorite, the second by a more acid granodiorite. The former is chiefly developed in the district between Santa Clara and Naña, and again west of Chosica.

In the granodiorite, moreover, occur numerous basic inclusions which appear to be xenoliths derived from the earlier diorite. Further, both types of rocks are penetrated by a later series of minor acid intrusions.

In studying the sequence of events indicated by these rocks, it is natural to make comparison with the evidence of successive periods of intrusion afforded by the corresponding plutonic complex of the Cerros de la Caldera, in the Arequipa district farther south. The diorite was there shown to be the second of three phases of intrusion, and it appears probable that this and the subsequent third phase are the equivalent of the two phases represented here. In each case they are succeeded by a phase of minor intrusions.

It may be recalled that it was to rocks of the first phase, unrepresented in the district now described, that I sought to trace the origin of the pebbles of granodiorite found in the basement

[1] Two successive phases of intrusion, of similar character to the above, were also observed in the plutonic rocks of the Trujillo district farther north.

conglomerate of the Cretaceous in the south, and if we are to regard an intrusion of this nature as the accompaniment of orographic movement it is not unreasonable to suppose that this phase took place during the post-Jurassic pre-Cretaceous folding.

Moreover, although prior to the intrusion of the second or dioritic phase the earlier rocks were evidently subjected to intense crushing, and in many cases were converted into true banded gneisses, it was shown that the interval of time which elapsed between the intrusion of the first and that of the second phase could not even approximately be conjectured.

If now, however, we apply the evidence gained from the district here described that the second and third phases are post-Cretaceous, and probably took place during the great Tertiary uplift of the Andes, it will be seen that this interval must have comprised the whole of the Cretaceous and early Tertiary periods; and we can regard the gneissic structure, which is not shared by the later rocks, as having been produced in those already in existence as a dynamic effect of this uplift.

Prof. Lisson[1] has given a detailed microscopic description of the granodiorites and diorites of the Lima district, and it is only necessary to add that they appear to be essentially similar to those which I have formerly described from Southern Peru.

When the eastern limit of the zone of plutonic rocks is reached near Matucana, the above-described normal facies of shallow-water Cretaceous deposits is found to have given place to the second or volcanic facies, consisting largely of bedded tuffs and agglomerates; a type of deposit that has a wide distribution in the Western Cordillera of Southern Peru.

These beds are strongly folded, and although they are occasionally interbedded with limestones and quartzites, in the absence of palæontological evidence from the latter it is impossible, without reference to other districts, to assign them definitely to any one geological period. Volcanic activity is known to have already been rife in Southern Peru in Jurassic times, and Forbes regarded the 'porphyritic conglomerate' of Bolivia as having also been formed during this epoch.

In my experience, however, with the exception of isolated occurrences such as the pillow-lava of the Morro de Arica, interbedded volcanic rocks are not as a rule found in the normal Jurassic sediments of the south, and they are also absent from the fossiliferous Jurassic rocks encountered in the district now described. Furthermore, it has been shown that volcanic rocks, except in the form of subsequent intrusions, are but seldom met with in the Lower Cretaceous Series of the Lima district. In later Cretaceous deposits, however, they are of widespread occurrence.

During the course of a further traverse, from Pacasmayo to Cajamarca, on the western slopes of the Cordillera Negra, thick beds of tuff and agglomerate together with lava-flows were found

[1] 'Geologia de Lima & sus Alrededores' 1907, pp. 95–106.

to alternate repeatedly with fossiliferous limestones of Cenomanian age, and interbedded lavas are frequently met with in similar deposits, both in Southern Peru and in the district here described.

Moreover, since these rocks are themselves penetrated by the Tertiary diorites and granodiorites, it appears probable that they constitute the first or volcanic phase of a great cycle of igneous activity which commenced in Upper Cretaceous times, though foreshadowed earlier, and was continued throughout the greater part of the Tertiary Era to culminate in the series of plutonic intrusions which form the batholithic core of the Andes. In the district covered by the section now described evidence of recent volcanic activity is wanting, though farther south volcanoes exist which are not yet extinct.

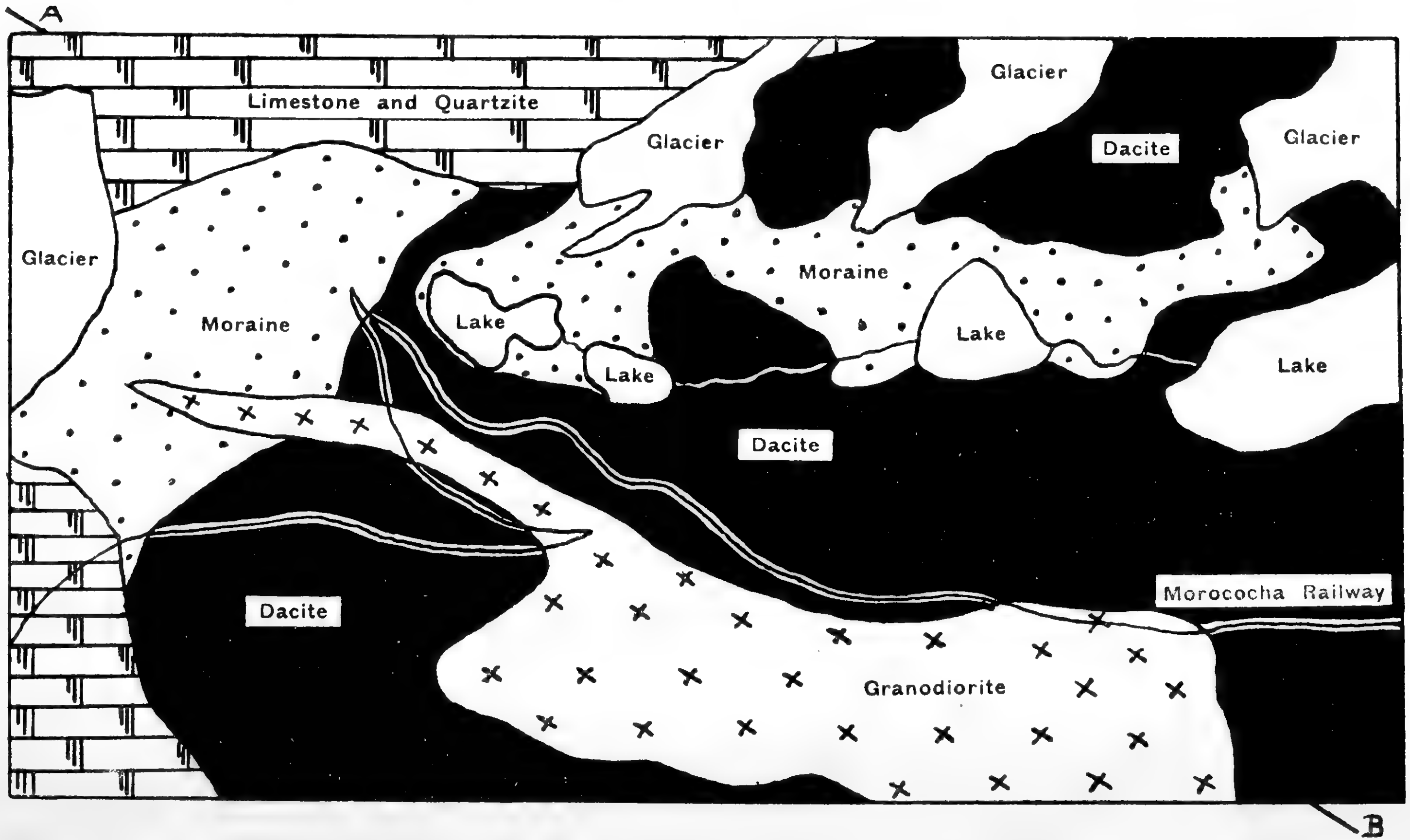
The western or Pacific slopes of the Cordillera are almost entirely formed by porphyritic agglomerates and tuffs of the volcanic facies, although a transition to the third or 'calcareous' facies is marked by the incoming at more than one locality of limestones and associated quartzites. Beds of this nature, for example, are seen dipping 75° south-westwards in the deep gorge above San Mateo, known as the Puente del Infernillo, and, again, forming an almost vertical junction with the agglomerate, at Tambo de Viso, where the latter rock is pierced by a broad dyke of quartz-porphyry. Nowhere, however, do they appear to contain fossils, nor does the calcareous facies become dominant until the summit of the range is passed.

At many places on the line of section other volcanic rocks, of an intrusive character, are also met with, which are distinct from, and obviously later than, those of 'contemporaneous' origin. These occur chiefly in the form of andesite- and dacite-necks, laid bare by erosion; but in no case could the form of any cone or superficial lava-stream be detected.

In keeping with the previously-expressed view that in this latitude the Andes have suffered their greatest compression, is the fact that plutonic rocks of the granodiorite core are here encountered almost at the summit of the mountain-range, more than 15,000 feet above sea-level. Although these are not actually exposed along the line of section, they crop out extensively a few miles farther north in the Morococha Valley, where their relationship to the overlying sediments and volcanic rocks is clearly displayed. A brief description of the structure of this district will serve to illustrate the part played by these rocks in the construction of the Cordillera.

The valley of Morococha, now the site of important mining operations, was formerly buried beneath a great mountain-glacier, the shrunken remnant of which occupies a small cirque at the head of the valley not far below the limit of perpetual snow. In addition, several small tributary glaciers still cling to the steep

Fig. 2.—*Geological sketch-map of the upper part of the Morococha Valley, on the scale of 1 : 20,000 (or approximately 3 inches to the mile).*



[The above map is orientated north and south.]

northern slopes of the valley, and terminate in large piles of morainic material. It is not intended, however, to describe here the magnificent example of glacial topography afforded by this district; and it will be sufficient to state that the floor of the valley now discloses a series of rock-steps occupied by a string of 'paternoster' lakes. The evidence afforded by glacially-striated rock-surfaces shows that the ice must have formerly been at least 500 feet thick.

Fig. 3.—Section from A to B, across the area represented in fig. 2; vertical scale : 1 : 10,000.

We are here concerned chiefly with the upper part of the valley, and a view taken from the south, looking directly across the lake known as Huacracocha, shows a large mass of dacite forming a jagged ridge, clothed in places with glaciers, terminating in the peak of Yanasinga (see Pl. XVIII).

At the head of the valley, however, above the Anticona lakes, well-defined Cretaceous limestones and quartzites are clearly visible, forming the denuded edge of what must once have been an extensive covering beneath which the igneous rock consolidated. The latter floors the greater part of the valley, and forms the rock-steps below the Anticona and Julia-Victoria lakes.

If we now descend the valley to the next rock-step below Huacracocha, known as the Alapampa ridge, we once more encounter stratified rocks, limestones, and quartzites, dipping westwards beneath the dacite, and forming the floor upon which it rests. At the margin of contact the limestones show pronounced evidences of metamorphism, and in places the igneous rock is bounded by a distinct selvage composed of compact green serpentine, fibrous chrysotile, and lime-garnets.

The mode of occurrence of this great mass of dacite is clearly different from that of the volcanic rocks found elsewhere in the district. It has, in fact, none of the features characteristic of a true lava, and, as it is essentially hypabyssal in origin, it might more accurately be termed a d a c i t e - p o r p h y r i t e. It is a compact, even-grained, dark-grey rock, and, although it contains small phenocrysts of felspar and ferromagnesian minerals, these never attain large dimensions. It has obviously consolidated beneath a considerable

thickness of overlying rock, and appears to have been injected into a series of Cretaceous deposits in the form of a huge laccolite, half of which only is now preserved.

A further phenomenon of deep-seated intrusion is also to be seen in the centre of the valley, immediately south of the railway at Kilometre 5 (from Ticlio), where, as shown in the accompanying sketch-map (fig. 2, p. 260) the dacite is itself penetrated by an irregular mass of coarse-grained, granitoid, plutonic rock, having the composition of an acid granodiorite. Although hand-specimens were collected showing the junction of the two rocks, the actual margin of contact is not sharply defined: the chief modification being a slightly-increased development of biotite in the granodiorite, where dacite-material has been assimilated. This, however, is by no means a constant feature.

In no instance was an included xenolith of the earlier rock encountered, and it therefore seems probable that the central or deeper-seated portions of the laccolite were still in a pasty or semi-molten condition when the plutonic invasion took place. Along the margins, however, consolidation was evidently already complete, for the dacite is here pierced by sharply-defined dykes of quartz-porphyry given off from the main mass, and differing from it only in texture and in the presence of porphyritic constituents. One of these dykes can be traced towards the head of the valley cutting across the railway, where the latter ascends in zigzag fashion. A second passes through the divide bounding the valley on the south, and crops out as a vertical wall on the side of the succeeding valley of Buenaventura.

The above-mentioned granodiorite is but a portion of a much larger mass which is met with farther down the valley at the foot of the cliffs below the lake of Morococha. The difference of level between the two exposures amounts to over 1000 feet; but this can be readily explained by assuming, as was doubtless the case, that the superficial portion of the deep-seated magma followed the line of weakness previously taken by the laccolitic intrusion, of which it was probably the parent body, and thus made its way much nearer to the surface.

The presence of plutonic rock at no very great depth below the present surface of the country, as indicated in the section here described, is based on the above-recorded facts.

We must now return to our main line of section. This attains its highest elevation near Ticlio, and is thence continued eastwards down the valley of the Yauli, a tributary of the Mantaro, which it enters just before Oroya. The country is here seen to differ vastly in character from that on the west of the watershed.

The relatively wide, flat-bottomed valleys, to a great extent choked with morainic material, which form so characteristic a feature of this high-level region, present a marked contrast with the deeply-cut precipitous gorges of the Pacific slopes; and rocks of volcanic origin, which up to this point have been the dominant

type, are here replaced by strongly-folded stratified deposits. The latter consist for the greater part of well-bedded, dark, bituminous limestones weathering to pale grey; but in places they are interstratified with beds of an arenaceous character, and with black carbonaceous shales containing workable coal-seams. Occasional masses of amygdaloidal lava of contemporaneous origin are also met with.

It may be recalled that in Southern Peru steeply-inclined or inverted beds were found to be the exception rather than the rule, and the folding apparently never reached that degree of intensity which is displayed in the rocks of this district, where vertical dips and overfolds are by no means uncommon.

In a section of this magnitude, constructed as the result of a somewhat rapid traverse, it has not been thought advisable to attempt more than a diagrammatic representation of the folding, for only by detailed mapping of the district, a task that would take many years to complete, can it be hoped to unravel the correct sequence of the rocks.

Owing to the nature and intensity of the Tertiary folding, it was not found possible to determine on purely stratigraphical grounds the existence of the great break in the succession between Jurassic and Cretaceous rocks which was shown to occur farther south. The two sets of deposits are here almost inextricably welded together in a great folded complex, and all traces of the pre-Cretaceous uplift and subsequent transgressive unconformity have been obliterated by the later folding. A study of the palæontological evidence, on the other hand, not only serves to show that the structure of the country is even more intricate than at first sight is apparent, but also furnishes strong grounds for supposing that the sequence is in reality not one of unbroken conformity.

The suggestion, which is so pronounced as almost to amount to a proof, that a great discontinuity is present is afforded by the frequent discovery in close juxtaposition of faunas of Lower Liassic and Middle Cretaceous age; whereas the beds which should normally intervene appear to be wholly wanting in this district. Further, if this gap in the sequence can be accounted for, as appears probable, on the theory of non-deposition, a ready indication is thus afforded of the source of the littoral leaf-bearing Lower Cretaceous beds of the coastal region.

Since it would serve no useful purpose to enumerate in detail all the localities at which fossils were found, I have confined myself to a generalized description of the three chief faunal horizons represented.

LIAS.

Fossils of Liassic age have already been recorded from the provinces of Yauli and Tarma, and the existence of deposits of much wider extent is suggested by the frequent occurrence of derived forms in the morainic drift of the Jauja valley. Along the line of section here described beds containing a characteristic

Liassic fauna are best displayed near the summit of the pass between Oroya and Tarma, where they consist of yellow, impure, sandy limestones, compact grey limestones with abundant chert-concretions, and glauconitic marls.

They here form one limb of a sharp overfold directed westwards; the dip changing from one of 80° south-westwards at the top of the cliff-face to 50° north-eastwards at the base. Fossils are abundant, and for the greater part are silicified and well-preserved. The most important determinative forms are comprised in the following list:—*Echioceras* cf. *raricostatum* (D'Orbigny), *Arietites* aff. *conybeari* Sowerby, *Terebratula (Lobothyris)* cf. *ovatissima* Quenstedt, and *Vola alata* Von Buch.

Palæontological Note.

ECHIOCERAS *cf.* RARICOSTATUM (D'Orbigny).

Specimens of this ammonite, though abundant, are somewhat poorly-preserved, but their widely-umbilicate, planulate form, coupled with the simple raricostate type of ribbing, leaves little doubt as to their correct determination, and they thus form a useful index to the age of the beds.

TEREBRATULA (LOBOTHYRIS) *cf.* OVATISSIMA Quenstedt. (Pl. XV, figs. 1–6.)

The general form of the shell, its various growth-stages, and the nature of the muscular impressions, suggest a typical Liassic species of the genus *Lobothyris*. The majority of specimens appear to be closely related to *T. ovatissima* of Quenstedt from the Sinemurian and Hettangian of Germany, which, as pointed out to me by Mr. S. S. Buckman, being a more advanced form than the later Domerian species *T. punctata*, must be regarded as belonging to a branch-stock and not as the ancestor of the latter.

The marginal contours of the shells that are grouped together here show considerable variation in different individuals. There is, however, no justification on this account for drawing specific distinctions between the various forms, for they appear to belong to a definite morphogenetic series, and differ merely in the stage of development attained when growth was arrested. The two main types of shell-outline (α and β) illustrated by F. A. von Quenstedt,[1] which for convenience may be termed the 'obese' and 'elongate,' are both represented in my collection, and their respective growth-stages are found to be parallel. The ontogenetic development, as represented by the single character of marginal contour, exhibits the following sequence of stages, which conform with the law for Terebratulid morphogeny propounded by Mr. S. S. Buckman[2]:—

Biconvex, Rectimarginate stage.
Uniplicate (Lophrothyrid) stage.
Sulciplicate (*Terebratula*) stage.

'Rectimarginate' forms are usually of small size (Pl. XV, fig. 3) and the majority of larger specimens have attained the uniplicate stage (Pl. XV, figs. 1 *a* & 1 *b*, 4). The more advanced or 'sulciplicate' stage is less common, but examples of both types of shell showing this character were found in a glauconitic marl at a somewhat higher horizon (Pl. XV, figs. 5 & 6).

Elongation of the shell, resulting in the second or 'elongate' variety

[1] 'Petrefactenkunde Deutschlands' vol. ii, Brachiopoden (1871) p. 328 & pl. xlvi, figs. 54–55.

[2] 'Brachiopoda of the Namyau Beds, Northern Shan States (Burma)' Mem. Geol. Surv. India: Pal. Indica, n. s. vol. iii, Mem. No. 2 (1917) p. 83.

commences in the 'rectimarginate' stage (Pl. XV, fig. 2). A further distinct sequence of changes is also illustrated by several specimens in my collection. In these the 'rectimarginate' stage is followed by a 'sulcate' or concavi-convex stage, in which the first sulcus is developed on the dorsal valve, the change taking place at an early period of growth. This 'sulcate' stage persists in the majority of adult forms, but in one example from the higher glauconitic horizon there is a suggestion of a transition to a 'paraplicate' (Holcothyrid) stage, incipient folds being developed at the sides of the dorsal sulcus.

In all the above-mentioned forms the beaks are typically Epithyrid, and in the elongate variety of shell there is a tendency towards the extension of the anterior (dorsal) margin of the rim over the dorsal umbo, a condition which Mr. Buckman has termed 'foramen labiate.'

The *Dallininæ* group is represented by a single example. This has a Mesothyrid beak with well-marked beak-ridges, and is provided with a strong median internal septum in the dorsal valve.

Owing to the silicified nature of the specimens, attempts to develop the muscular impressions by burning, the method advocated by Mr. Buckman, were not successful; but it was found that, by prolonged immersion in dilute acid, much of the interior filling could be dissolved and the shell thereby rendered semi-transparent, when the muscle-scars became visible.

These in forms of small size are narrow and sub-parallel; but in larger examples they appear to be somewhat divergent, and are swollen at the anterior end. A faint median septum is also visible.

VOLA ALATA Von Buch.

This is a very abundant and characteristic species, and, according to W. Möricke,[1] is very common in the Middle and Upper Lias, though rare in the Lower. For figures and description of typical specimens, see C. E. Bayle & H. Coquand, 'Mémoire sur les Fossiles Secondaires recueillis dans le Chili par M. Ignace Domeyko' Mém. Soc. Géol. France, ser. 2, vol. iv (1851) p. 14 & pl. v, figs. 1–2.

ALBIAN.

A reference to that part of the section which lies between Yauli and Oroya shows that the beds are here bent into a great asymmetrical synclinal fold, of which the eastern limb is the more steeply inclined. The gently-dipping beds of the western limb are readily accessible in a cutting on the railway at Saco, where they consist of dark bituminous limestones containing numerous fossils of Albian age.

The following list was recorded from this locality:—

Diploceras cornutum (Pictet).
Brancoceras aff. *varicosum* (Sowerby).
Schlœnbachia multifida Steinmann.
Schl. cf. *acutocarinata* (Shumard) Böse.
Schl. cf. *belknapi* (Marcou) Böse.
Schl. cf. *ventanillensis* (Gabb).
Acanthoceras cf. *lyelli* (Leymerie).
Nucula peruana Gabb.
Cyrena huebneri Steinmann.
Tellina peruana Gabb.
Protocardium appressum Gabb.
Pinna cf. *robinaldina* D'Orbigny.
Astarte sp.
Trigonia sp.
Tylostoma cf. *chihuahuense* Böse.

Similar beds containing many of the forms enumerated above are also met with between Rumichaca and Yauli, and again at Pachachaca.

[1] Bibliography, § IV, No. 43, p. 41.

Palæontological Note.

The most abundant and characteristic forms in the foregoing list are Ammonites of the acutocarinate falcicostate type. These constitute a well-defined group which appears to have a wide distribution in the Western Hemisphere, having been described from the United States, Mexico, Peru, and Brazil, while in Europe it is represented by allied forms such as *Schlœnbachia royssiana* (D'Orbigny).

The existing names of the species united here are not sufficient even to cover all the forms already figured, and numerous others still remain to be described. Dr. L. F. Spath, to whom I am indebted for much valuable assistance and advice, is, however, at present engaged on a much-needed revision of the group; and when this is completed many of the difficulties of nomenclature will doubtless be solved. In the meantime, my remarks on the Peruvian examples must be regarded as purely tentative; for, as Dr. Spath has suggested, many forms may prove to be mutations characteristic of various horizons, and, until the zonal sequence has been fully worked out, any definite specific determinations might only lead to further confusion. Unfortunately, the figures of many types described by earlier writers are unsatisfactory, and for this reason the correct identification of the various forms present in my collection, representing probably at least six distinct species, is by no means easy.

Another factor that must also be taken into consideration, to which, in my opinion, sufficient importance has not hitherto been attached, is the great dissimilarity that exists in some forms between specimens in which the outer shell is preserved and those in which it has been removed, exposing the underlying cast. My meaning will be best understood by reference to the specimen figured in Pl. XVI, fig. 3. In fig. 4, which is a portion of the same specimen (natural size) with the shell preserved, the ribs are seen to be comparatively broad and flat, and to be separated by narrow sulci; the surface in fact being not unlike 'Bedford cord.' When, however, as near the broken end of the last whorl in fig. 3, the outer shell is missing, the ornament presents quite a different appearance. The pseudo-ribs, which are in reality casts of internal corrugations, are much more strongly defined, and are separated by furrows of equal width (compare also the figured cast of another specimen, Pl. XVI, fig. 1).

It is thus, I think, clear that specific descriptions based on the cast may differ radically from those based on the complete shell. That the former method has been employed in many cases, without any statement to that effect, or reference to the state of preservation, is shown by the clear definition of the septal suture-lines in the figured examples. These, of course, would not be visible if the outer shell had been preserved.

The earliest-known species belonging to this group is *Ammonites peruvianus* described from Peru in 1839 by C. L. von Buch.[1] In 1858 this species was again figured by J. Marcou from the Elm Fork River (Texas)[2] and identified by him with *A. acutocarinatus* of Shumard. In his description (*loc. cit.*) the ribs are stated to be simple, and much larger than the intervals that separate them; and, since no indication of suture-lines appears in the figures, it is probable that he was dealing with specimens in which the shell was preserved. The type-figure of *A. acutocarinatus* Shumard[3] is, however, very unsatisfactory, and has led to several different interpretations being given of it by later authors. The specimen has the appearance of being in the form of a cast, and bears not the least resemblance to that figured by Marcou.

Another species from Peru is *A. carbonarius* Gabb, collected by Raimondi

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[1] See Bibliography, § IV, No. 38, pp. 5–6.

[2] 'Geology of North America' p. 34 & pl. v, figs. 1, 1 *a*, 1 *b*.

[3] B. F. Shumard, 'Natural History of the Red River of Louisiana' App. E, Palæontology (1853) p. 209 & pl. iii, fig. 1.

from the coal-mine of Pariatambo and incorrectly assigned by Gabb to the Lias.[1] According to the description there given, the surface of the shell is marked by numerous regular ribs, slightly flattened on their upper surface, and having concave interspaces nearly as large as the ribs. This feature, however, does not appear to be borne out by the figure, in which the type of ornamentation seems to be very similar to that exhibited by the specimen illustrated here (Pl. XVI, fig. 4).

A further type from the same locality (Pariatambo), differing from that just mentioned in the regular bifurcation of the ribs, is that described by Prof. G. Steinmann as *Schlœnbachia acutocarinata* (Shumard) Marcou, variety '*multifida*,' Steinmann thereby accepting Marcou's interpretation of Shumard's type. A comparison of Steinmann's figure[2] with that of Shumard[3] shows that there is no justification for regarding the former as a variety of the latter, since Shumard's type is distinctly costate at a diameter when *Schlœnbachia multifida* has closely-set flattened ribs. The Peruvian shell may, therefore, be regarded as a distinct species.

Steinmann also records other examples from Saco, between Oroya and Pachachaca, near Yauli, the same locality as that from which my specimens were obtained. If, then, I am justified in regarding these as topotypes, Steinmann's figure calls for a certain amount of emendation.

SCHLŒNBACHIA MULTIFIDA Steinmann. (Pl. XVI, figs. 2–5.)

In the nature of the ribbing, degree of involution, and whorl-section, the type agrees closely with my examples; but it is clear that the specimen illustrated is in the form of a cast, and the depth of the sulci is thereby exaggerated.[4] This is borne out by the fact that distinct ribbing is shown on the inner whorls, whereas when the outer shell is preserved, it is, as can be seen in my figure (Pl. XVI, fig. 2) on the left of the umbilicus, at this diameter almost smooth or marked only by fine striæ.

Again, in the type-figure the ribs are indicated as widening gradually towards the periphery, while in my examples the greatest breadth occurs on the flank of the shell, where the forward curvature of the ribs commences, whence they taper to their peripheral termination. This sickle-shaped curvature, moreover, is but poorly shown in Steinmann's illustration.

It was found that if a line be drawn joining the centre of a shell, of the same diameter as the type, with the peripheral termination of any one rib, this will cut as a rule five other ribs immediately anterior to it, as shown in the subjoined diagram (text-fig. 4, A, p. 268) and also, though less clearly, in Pl. XVI, fig. 3, at the point indicated by an arrow. [Pl. XVI, fig. 4 represents a portion of the lateral surface of the same specimen, and therefore does not show the peripheral curvature of the ribbing.]

Further, in the forms collected by me the branching of the ribs takes place nearer the umbilical margin than is shown in the type-figure.

Despite these apparent differences I regard the specimens figured here (Pl. XVI, figs. 2–5) as representative of Steinmann's species '*multifida*,' and I am of the opinion that *Ammonites carbonarius* of Gabb, if not identical, is at least a closely-related form.

One other feature remains to be noticed: namely, the peculiar character of the siphuncle. This, in place of the usual circular section, has the outline shown in the diagram: the shape being that of a laterally-compressed ellipse, somewhat swollen at its inner end. This is not a chance feature due to crushing, nor is it a mere infilling of the hollow keel above the true siphuncle, but is a constant feature in all those specimens where the latter is visible (see fig. 4, D, p. 268).

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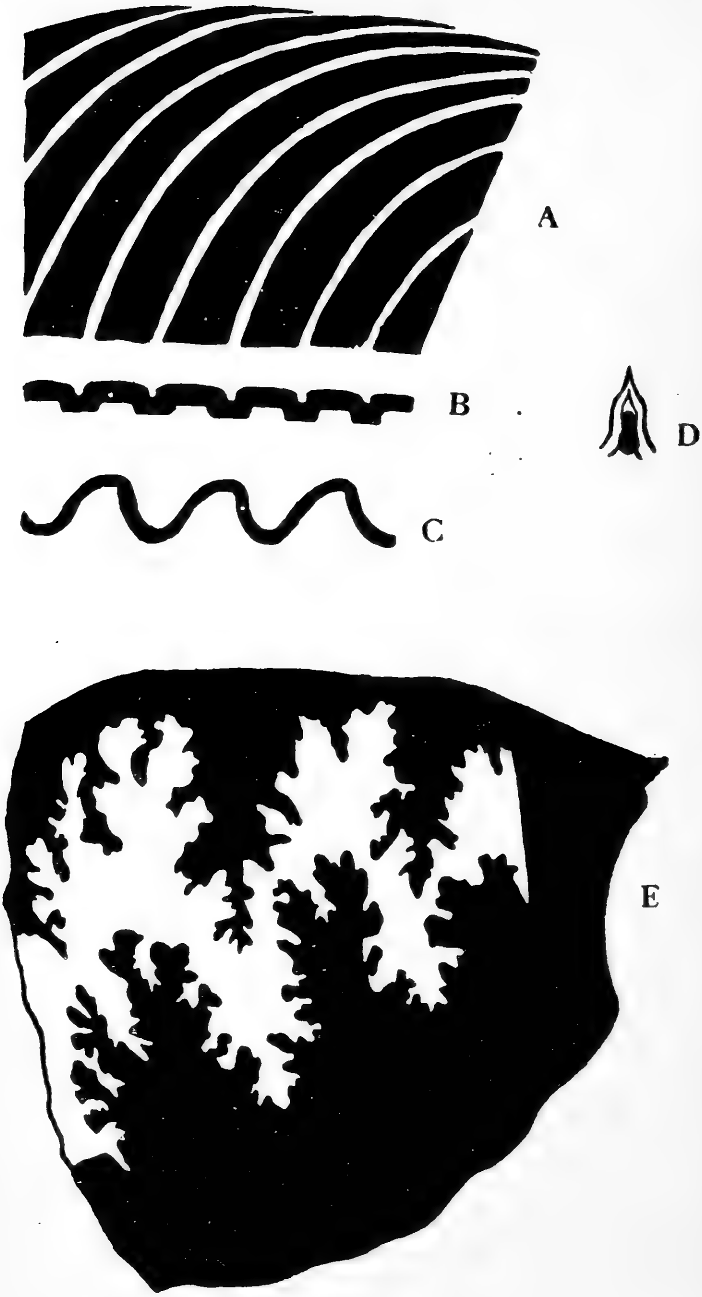
[1] See Bibliography, § IV, No. 40, p. 269 & pl. xxxviii, figs. 2, 2 *a*, 2 *b*.
[2] Neues Jahrb. vol. ii (1881) pl. vii, fig. 1.
[3] *Op. supra cit.* pl. iii, fig. 1.
[4] A condition represented in my figs. 2 & 5.

Fig. 4.



[A = Diagram showing peripheral forward curvature of ribs in *Schlœnbachia multifida* Steinmann (see p. 267).

B, C = Diagrammatic cross-sections of shells of '*multifida*' and '*belknapi*' types (see p. 269).

D = Diagrammatic view of siphuncle in *Schlœnbachia multifida* (see p. 267).

E = Septal - suture line of *Schlœnbachia* cf. *acutocarinata* (Shumard) Böse.]

In 1912 a revision of Steinmann's Peruvian material was made by O. Schlagintweit[1] which resulted in the grouping together of a number of widely-differing forms under the title of A. d'Orbigny's species '*Schlœnbachia royssiana*,' and again in 1913 they were once more united by Dr. C. I. Lisson as *Schlœnbachia peruana* Von Buch. That such drastic treatment was quite unwarranted is apparent from the number of distinct forms represented in my own collection. Of these several may be tentatively referred to types figured by Dr. E. Böse from Mexico.[2] Here are included species with widely-spaced costæ, the outer shell of which, unlike that of '*multifida*,' conforms closely with the internal corrugations shown by the cast (compare the cross-sections of the shells illustrated in fig. 4, B & C, p. 268).

In most of the forms possessing broad sulci common to both shell and cast, the posterior faces of the ribs have a gentle slope with a convex curvature; while the anterior faces are, as a rule, steep, and either plane or slightly concave (see Pl. XVII, fig. 1). In '*multifida*,' where the ribs are flattened and close-set, the underlying ribs of the cast have an almost rectangular cross-section.

SCHLŒNBACHIA sp. (*cf.* ACUTOCARINATA Böse *non* Shumard).

The example illustrated in Pl. XVI, fig. 1, although closely related to '*multifida*,' differs from it in the possession of more widely spaced ribs with less regular dichotomy. At the margin of the almost vertical umbilical wall, the ribs, moreover, have a pronounced backward sweep; whereas in '*multifida*' they are not only almost radial in direction at their origin, but about twice as numerous for the same length of margin. It appears to have a certain resemblance to the form figured by Dr. E. Böse as 'aff. *acutocarinata*' Shumard[3]; but this again appears to differ very widely from Shumard's original type, and whether Böse is correct in his interpretation of the latter is extremely doubtful. His figured example is, like mine, in the form of a cast, but traces of adhering shell suggest that the true ornament is of the open-ribbed type, intermediate between '*multifida*' and '*belknapi*' (see below). A comparison of the suture-lines shows that the lateral lobes are somewhat deeper and narrower in the Peruvian form, and in this respect it more closely resembles *Schlœnbachia* cf. *belknapi* Böse (*non* Marcou).[4]

Other forms with still more widely spaced ribs are also represented in my collection. These are more evolute in character, and possess simple ribs with (in general) a less-pronounced forward curvature. One example (Pl. XVII, fig. 3) characterized by thin, sharp ribs, at first almost straight and then expanding rapidly where they bend forward near the periphery of the shell, appears to be analogous to the Mexican species, *Schl. chihuahuensis*.[5] In Böse's description of the type the ribs are stated to curve strongly forward in the upper quarter, diminishing in height to disappear near the keel; but, except in the peripheral view (pl. viii, fig. 1) which agrees closely with mine, this curvature is not clearly shown in the illustration (pl. vii, fig. 3), where the ribs appear to be almost straight throughout their length.[6]

SCHLŒNBACHIA *cf.* BELKNAPI Böse (*non* Marcou).

The most pronounced development of ribbing is that shown by the specimen figured in Pl. XVII, fig. 1, which represents a fragment of the cast of a large

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[1] See Bibliography, § IV, No. 50.

[2] 'Monografia Geologica & Paleontologica del Cerro de Muleros' Bol. Inst. Geol. Mex. 25 (1910).

[3] *Ibid.* p. 65, pl. i, fig. 3 & pl. ii, figs. 1–3.

[4] See E. Böse, *op. cit.* pl. vii, fig. 5.

[5] *Id. ibid.* p. 73 & pl. vii, fig. 3, pl. viii, fig. 1.

[6] Compare J. Marcou's figure of *Ammonites gibbonianus* Lea, 'Geology of North America' 1858, pl. ii, fig. 2 *a*.

individual. The deep sulci are here considerably broader than the ribs, and the latter are characterized by steep anterior faces which may be likened to a series of escarpments. Further, although the growth-lines of the shell, when this is preserved, show a strong forward curvature near the periphery, the ribs themselves, especially in the cast, run almost straight towards their termination.

This form appears to bear a close resemblance to *Schlœnbachia belknapi* (Marcou) as figured by Böse,[1] whose interpretation of the type, however, is somewhat different from that of its original author.

Since Böse's illustration of the suture-line of a Mexican example is almost identical with that of one of the closer-ribbed specimens figured here (Pl. XVI, fig. 1), it is probable that these coarsely-ribbed shells represent phylogenetic old-age forms of a close-ribbed stock.

The small individual figured here (Pl. XVII, fig. 2) is possibly a youthful form of *Schl. belknapi*. The ribs are here seen to be relatively widely spaced, even at a very early stage of growth.

DIPLOCERAS CORNUTUM (Pictet).

The occurrence of this ammonite is of considerable interest, as pointed out to me by Dr. L. F. Spath, in that it affords evidence for assuming the horizon of the beds to be just below the level of the '*cristatum*' zone.

The species is represented in my collection by a well-preserved almost complete half of a shell having about the same diameter as the type. F. J. Pictet's original figure[2] shows the latter as possessing smooth inner whorls; whereas in my specimen these are distinctly costate, even at a very early stage of growth. In his peripheral view, moreover, the costæ run at right angles to the keel, while in the Peruvian shell these have a pronounced forward curvature. In other respects, it agrees closely with the type.

SCHLŒNBACHIA VENTANILLENSIS (Gabb). (Pl. XVII, fig. 4 & Pl. XV, figs. 8 *a*–8 *b*.)

The original type of this species was described by Gabb in 1877, and it was then correctly stated that, while in the young form the ornamentation consisted solely of fine striæ, these were replaced in the adult shell by strong simple costæ, each giving rise to a pair of pronounced tubercles, the change being comparatively sudden, and taking place at about a diameter of 1 inch. The species was, at that time, incorrectly assigned to the Lias. In 1881, Prof. Steinmann redescribed a young smooth-shelled example from the same locality as a new genus, to which he gave the name *Mojsisovicsia dürfeldi*. Later, in rectifying the error, he sought to prove the identity of the Peruvian species with *Ammonites inflatus* Sowerby. A comparison with Sowerby's original type-specimen, however, shows that the two are quite dissimilar.

Reference must also be made to a number of examples figured by Dr. C. I. Lisson.[3] One specimen shows the transition from the smooth to the costate stage taking place at a very early period of growth (pl. xvi, fig. 4), the adult type of ornamentation being fully developed at a diameter when the numerous examples in my collection are still in the smooth stage (compare Pl. XV, fig. 8, which may be taken as an average specimen).

In the young forms figured by Dr. Lisson (pl. xv) the back is described as being 'rounded, with insignificant keel'; but, as is clearly shown by the specimen illustrated here (Pl. XV, fig. 8 *b*), the latter often becomes pronounced at a comparatively early stage, and its appearance is usually accompanied by a slight flattening of the dorsal surface on each side.

[1] Bol. Inst. Geol. Mex. 25 (1910) pls. vi & vii.

[2] 'Mollusques Fossiles . . . . dans les Grès Verts des Environs de Genève pt. i, Céphalopodes (1847) p. 93 & pl. viii, figs. 6 *a*–6 *c*.

[3] 'Ammonites del Peru' Lima, 1908, pls. xv & xvi.

The morphogenetic stages of growth may be summarized as follows:—

Youth.—Smooth shell with falciform striæ.

Adolescence.—Shell with simple ribs extending continuously to a dorsal row of tubercles.

Maturity.—Shell with an inner row of tubercles developed by lateral thickening of the ribs (usually commencing at about the tenth). These are separated from the dorsal tubercles by a portion of the shell in which the ribbing is suppressed.

In the peripheral views of adult forms given by both Gabb[1] and Lisson,[2] the ribs on the peripheral side of the dorsal row of tubercles are shown as being prolonged towards the keel with a strong forward curvature. This particular feature, however, is not exhibited by any of the specimens in my collection, in all of which the ribs tend to die out on the dorsal surface.

It was noticed in one example that at a comparatively late stage of growth the ribs were continuous to the dorsal surface, where each expanded slightly to form a single laterally-compressed tubercle, thus preserving the adolescent character noted above. Occasionally, however, an individual rib may show a slight elevation above its neighbours, though no lateral tubercles are developed. In this respect the ornamentation is not unlike that of *Ammonites delaruei* D'Orbigny, to which, as suggested by Dr. Lisson, *Schlœnbachia ventanillensis* probably is closely related.

CENOMANIAN.

Although there is but little variation in the lithological characters of the limestones over the greater part of this district, it is probable that more than one subdivision of the Cretaceous System is present, for certain beds are met with at various localities which contain a fauna, quite distinct from that recorded above, characterized by an abundance of echinoderms and lamellibranchs, and by an almost complete absence of ammonites. This fauna is regarded by Dr. Lisson as being of Aptian age; but, after comparison with a closely-related assemblage of species described by Dr. Böse from Mexico, and with many forms that appear to be their nearest European equivalents, I am of the opinion that the horizon represented is above rather than below the Albian, and may with more reason be assigned to the Cenomanian. At Kilometre 225, between Oroya and Huari, on the Huancayo railway, these beds were found overlying the typical ammonite-beds of the Albian.

Such an occurrence cannot, however, be taken as definite stratigraphical proof that they are of later date, for the district is one that has been subjected to much disturbance, and inversion of the strata would not be entirely unexpected.

The chief forms that characterize these beds are comprised in the following list:—

Enallaster texanus (Rœmer).
Holectypus planatus Rœmer.
Diplopodia hilli Clark.
Diplopodia texana (Rœmer).
Echinobrissus subquadratus D'Orbigny.
Pecten (Neithea) quadricostatus Sowerby.
Pecten cf. *chihuahuensis* Böse.
Liopistha (Psilomya) gigantea (Sowerby).
Plicatula cf. *inflata* Sowerby.
Lima (Mantellum) cf. *mexicana* Böse.
Exogyra cf. *conica* Sowerby.
Modiola sp.
Natica aff. *collina* Conrad.
Turritella granulata Sowerby, var. *cenomanensis* D'Orbigny.

[1] *Op. cit.* pl. xxxix, fig. 2 *a*.

[2] *Op. cit.* pl. xvi, fig. 1 *b*.

Palæontological Note.

ENALLASTER TEXANUS (Rœmer) = E. PERUANUS Gabb.

The Peruvian form originally described by Gabb[1] is probably identical with F. Rœmer's North-American species.[2]

A closely-allied species is also that described from Mexico by Dr. Böse, as *Enallaster bravoensis*.[3] Many of these figures agree in essential details with those of Peruvian fossils illustrated by L. Sommermeier.[4]

HOLECTYPUS PLANATUS Rœmer.

Two distinct forms of this shell are represented in my collection. The first agrees closely with the type illustrated by Rœmer[5] and appears to be closely related to Dr. E. Böse's Mexican species, *Holectypus limitis*.[6] The second, from the limestones of Yauli, which appear to lie below the Albian ammonite-beds, was never found in conjunction with any of the species mentioned in the above list, and is probably identical with the variety figured by Sommermeier as *H. planatus* Rœmer var. *numismalis* (Gabb),[7] although the original specimen figured by Gabb is a much larger form.[8] The two forms, therefore, may eventually prove to be distinct species.

LIOPISTHA (PSILOMYA) GIGANTEA (Sowerby).

A very characteristic shell occurring in great abundance, and agreeing closely with Sowerby's type from the Upper Greensand of Blackdown (zone of *Schlœnbachia rostrata*) as figured by Mr. H. Woods.[9]

EXOGYRA *cf.* CONICA Sowerby.

Large specimens of this shell, which possibly represents a late mutation of Sowerby's species, were found at a somewhat higher horizon than that of the echinoderm-beds. Their position, therefore, is analogous to that of the large Mexican form, *Exogyra ponderosa*, although the two species are quite distinct.

The following table gives a suggested correlation of the Cretaceous rocks of the Oroya district with those described by Dr. Böse from the Cerro de Muleros (Mexico). It is intended to show the similarity of the faunal assemblages in the two areas, but must not be taken to indicate that the species are regarded in every case as being identical. The subdivisions are those recognized by Dr. Böse :—

[1] See Bibliography, § IV, No. 40, vol. viii, p. 301 & pl. xliii, figs. 4–4 *c*.

[2] 'Die Kreidebildungen von Texas & ihre Organischen Einschlüsse' 1852, p. 85 & pl. x, fig. 3; see also W. B. Clark, 'The Mesozoic Echinodermata of the United States' Bull. U.S. Geol. Surv. 97 (1893) p. 78 & pl. xxxix, figs. 2 *a*–2 *g*.

[3] 'Monografia Geologica & Paleontologica del Cerro de Muleros' Bol. Inst. Geol. Mex. 25 (1910) pl. xli, figs. 5–10, pl. xlii, figs. 2–12, & pl. xliii, figs. 1, 2, 6, 7.

[4] Bibliography, § IV, No. 52, pl. xv, figs. 4–6.

[5] *Op. cit.* pl. x, fig. 2 *c*.

[6] *Op. cit.* pl. xxxvi, figs. 3–6 & pl. xxxvii, figs. 1–8, p. 159.

[7] *Op. cit.* pl. xv, figs. 1–3 [*Discoidea*].

[8] Bibliography, § IV, No. 40, pl. xliii, figs. 3–3 *b*.

[9] 'Cretaceous Lamellibranchia of England' Palæont. Soc. Monogr. vol. ii (1913) p. 257 & pl. xliii, figs. 3–4, pl. xliv, figs. 1–2.

Sub-division.	Mexico.	Peru.	Horizon.
7.	*Exogyra ponderosa* Rœmer.	*Exogyra* cf. *conica* Sowerby (large forms).	*Exogyra* Beds.
6.	*Enallaster bravoensis* Böse. *Turritella granulata* Sowerby, var. *cenomanensis* D'Orbigny. *Lima (Mantellum) mexicana* Böse.	*Enallaster peruanus* Gabb = *E. texanus* (Rœmer). *Turritella granulata* Sowerby, var. *cenomanensis* D'Orbigny. *Lima (Mantellum)* cf. *mexicana* Böse.	*Enallaster* Beds of Huari.
5.	*Holectypus limitis* Böse. *Pseudodiadema (Diplopodia)* cf. *variolaris* Brongniart. *Natica* aff. *collina* Conrad. *Pecten chihuahuensis* Böse. *Vola quinquecostata* Sowerby = *Pecten quadricostatus* (Sowerby) Rœmer.	*Holectypus planatus* Rœmer. *Pseudodiadema (Diplopodia) texanum* (Rœmer). *Natica* aff. *collina* Conrad. *Pecten* cf. *chihuahuensis* Böse. *Pecten (Neithea) quadricostatus* Sowerby.	
4.	*Schlœnbachia* cf. *belknapi* Marcou.	*Schlœnbachia* cf. *belknapi* (Marcou) Böse.	Ammonite-Beds of Saco.
3.	*Schlœnbachia* cf. *belknapi* Marcou.	*Schlœnbachia multifida* Steinmann.	
2.	*Schlœnbachia* aff. *acutocarinata* (Shumard) Marcou. *Pinna guadalupæ* Böse. *Tylostoma chihuahuense* Böse.	*Schlœnbachia* cf. *acutocarinata* (Shumard) Böse. *Pinna* cf. *robinaldina* D'Orbigny. *Tylostoma* cf. *chihuahuense* Böse.	

As we commence the descent of the eastern slopes of the Cordillera, we find that this great Mesozoic limestone series extends almost as far as Tarma, where deposits of Liassic age rest upon an older series of conglomerates and quartzites with occasional bands of dolomite, which Prof. Steinmann (relying solely on lithological evidence) suggests are of Triassic age. In the absence of fossils, however, it does not at present seem justifiable to separate them definitely from the Jurassic deposits which overlie them conformably.

From this point to the end of our line of section we have to deal with rocks that are of Palæozoic or even earlier age. Relying on the evidence obtained from regions farther south, I regard it as clear that these rocks must have been subjected to several distinct periods of orogenic movement, with the result that they have been in many cases highly metamorphosed.

The structure of the country is thus further complicated, and, in the almost complete absence of fossil remains, the correct sequence of the deposits is by no means easy to determine. Certain apparent anomalies in the succession may be explained either by a system of thrust-planes along which movement has taken place in an easterly

direction (towards the exterior of the chain) or by the 'pinching-in' of steeply inclined folds and the consequent preservation of younger beds among those of earlier date over which they were originally transgressive.

In the neighbourhood of Tarma the above-described Mesozoic rocks rest unconformably on a series of strongly-folded olive-green and red shales, which are assigned by Steinmann to the upper part of the Lower Silurian. They are, however, quite distinct from the black, graptolite-bearing, Ordovician shales of the Carabaya district of Southern Peru, and in lithological character they more closely resemble the Devonian rocks of the region north of Lake Titicaca. Since they appear to contain no fossils, I have deemed it inadvisable, however, to assert a definite opinion as to their age, and have recorded them here provisionally as Upper Palæozoic.

Near the village of Acobamba these shales rest with apparent conformity upon a series of limestones, quartzites, and conglomerates. These in turn are succeeded by phyllites, which, when traced towards the east, become increasingly metamorphosed until they assume the character of true mica-schists.

In the midst of this metamorphic series, a short distance west of Palca, occur black crystalline limestones apparently but little altered. Their presence here, according to Prof. Steinmann, may be accounted for by means of a steeply-inclined thrust-plane along which the older rocks have been carried over them from the west. It is possible, however, that they occur in a normal succession, and have remained comparatively unaltered; while the less-resistant argillaceous shales, associated with them, have been converted into phyllites.

The age of these limestones is by no means certain. Steinmann assigns them to the Carboniferous, from the reputed discovery in the neighbourhood of *Lonsdalea* and *Productus*. The locality from which were derived the specimens that led him to form this opinion is, however, unknown, for they were presented to him during the course of his journey, without, it appears, any definite record of their origin. While it is possible that his deduction is correct, it is regrettable that a note explaining the exact value of such evidence was not inserted in his account of the district. Between Palca and Carpapata the steep sides of the valley are formed almost entirely of granite, veined with both large and small intrusions of porphyry, and as we approach Huacapistana this is seen to be replaced once more by metamorphosed sediments in the form of mica-schists.

Another and more extensive outcrop of granite is met with immediately below Utcuyacu, where it exhibits proof of having been subjected to intense dynamic crushing, with the consequent development of typical gneissic structure. It is important to note that this is a white rock, quite distinct, not only in lithological character, but also probably in geological age, from the red granite of the Perene district, to be described below. It is clearly of later date than the surrounding strata, for its intrusive character can be

proved at more than one locality. The more pronounced metamorphism of the mica-schists, as compared with that of the phyllites, may, I think, be explained on the assumption that the former represent rocks which had already undergone a certain amount of change as a result of the granitic intrusion before being subjected, together with the surrounding unaltered shales, to the dynamic crushing which later affected the whole series, including the granite itself.

Beyond Utcuyacu the outcrop of the granite cuts across the strike of strongly-folded limestones, similar in character to those above Palca. In the rock-cut on the trail between San Lorenzo and the hill known as Pan de Azucar (sugar-loaf), these are seen to contain casts of a brachiopod, filled with white calcite. These casts are of large size, in many cases measuring 3 inches or more in depth, and the concave-convex form of their cross-section is strongly suggestive of a *Productus* of the '*giganteus*' type. Although such evidence can hardly be claimed to be satisfactory, it nevertheless may be regarded as furnishing some support to Prof. Steinmann's view that the limestones of Palca are of Carboniferous age.

As is the case in that locality, they are followed here by phyllites, the junction of the two rocks, owing to the intense nature of the folding, being nearly vertical. These phyllites, though obscured in places by the thick growth of forest vegetation, can be traced as far as San Ramon, where, without any indication of increased metamorphism, they overlie a coarsely-crystalline red granite which was proved to crop out continuously to a point some distance beyond the eastern limit of our section.

This granite is a typically alkaline rock, and differs markedly in composition from the granodiorites that are found in the heart of the Cordillera. It is very uniform in character over a large tract of country, and although, in this district, at least, there appears to be a complete lack of positive evidence as to its geological age, the presence of practically unaltered sediments in close proximity to so enormous a mass of plutonic rock can hardly be accounted for, except on the assumption that the origin of the latter was antecedent to their deposition.

It must, therefore, date from at least Lower Palæozoic times, and, as was suggested in the case of the plutonic rocks of the Inambari district, it has evidently been an important factor in checking the advance of the folded chains into the area of the Brazilian platform. It may therefore be regarded as belonging to an extra-Andean igneous province, characterized by rocks of 'Atlantic' facies.

Petrographical Note.

[Numerals in parentheses indicate microscopic slides and hand-specimens preserved in the University Museum, Oxford.]

(A. 152.) Granite.—Perene.—A coarse-grained, holocrystalline pink rock of granitic texture, consisting almost entirely of quartz and felspar, to which the coloured minerals are quite subordinate (sp. gr. = 2·58).

Microscopic characters.—Quartz and felspar make up the bulk of the rock, the coloured minerals, with the exception of a little magnetite, consisting solely of secondary hæmatite.

The felspar consists of perthitic intergrowths of orthoclase and albite, the latter showing very narrow twin-lamellæ and a refractive index considerably lower than that of quartz. Maximum extinction-angle (in sections cut perpendicular to the lamellæ) = 11°.

Ferromagnesian minerals typically absent.

Zircon in small brilliantly-polarizing prisms is the only other accessory mineral represented, in addition to the magnetite.

(A. 151.) Granite.—Utcuyacu.—A medium-grained white rock of granitic texture, consisting chiefly of quartz, white felspar, and biotite (sp. gr. = 2·68).

Microscopic characters.—Quartz is very abundant.

The felspars comprise both orthoclase and plagioclase, the former being slightly in excess of the latter, although the relative proportion varies somewhat in different parts of the same slide. A small amount of microcline with typical cross-hatching is also present. The bulk of the plagioclase lies between oligoclase and andesine; it shows low extinction-angles and a refractive index very close to that of quartz.

The ferromagnesian minerals comprise chestnut-brown biotite, showing occasional bending of the lamellæ, and a smaller amount of green hornblende.

Accessory minerals comprise sphene and zircon.

The above-described rock differs from the typical granodiorites of the Cordillera in the following respects:—The greater abundance of quartz; the presence of microcline; the much smaller proportion of ferromagnesian minerals; and the complete absence of iron-oxides.

(A. 150.) Granitoid Gneiss.—Near Huacapistana.—A specimen of the Utcuyacu granite in which typical gneissic structure has been developed.

Microscopic characters.—The large allotriomorphic crystals of quartz seen in the above rock have been broken up into a granular mosaic.

The plagioclase shows fracture and distortion of the twin-lamellæ.

The hornblende seems to have entirely disappeared; but there is a greatly-increased quantity of biotite, which has segregated into layers giving a banded appearance to the rock.

A considerable amount of muscovite has also been developed, and a few small isotropic crystals of garnet are present.

III. General Summary and Conclusions.

The foregoing paper, which is a third contribution to a series by the present writer dealing with the geology of Peru and a part of Bolivia, illustrates by means of a horizontal section across the Cordillera the structural features of the country between the port of Callao and the Rio Perene.

The section commences at the Island of San Lorenzo, which is formed of westward-dipping strata of Lower Cretaceous (Neocomian) age, consisting chiefly of shales and quartzites of shallow-water or littoral origin containing numerous plant-remains. They here form one limb of an anticlinal fold, of which the corresponding eastern limb is met with on the mainland between Callao and Lima. Although igneous rocks of contemporaneous origin are rare, subsequent intrusions in the form of dykes and sills of augite-andesite are of common occurrence.

In the immediate neighbourhood of Lima we encounter the great Tertiary batholithic core of granodiorite, cutting sharply across the dip of these Cretaceous rocks and causing pronounced metamorphism along the margin of contact. From this point plutonic rocks crop out almost continuously as far as Matucana. The intrusion appears to have taken place in two distinct phases: the first represented by a diorite, the second by a more acid granodiorite; and these are compared with the corresponding phases formerly described from the rocks of the Cerros de la Caldera, near Arequipa.

Beyond Matucana we meet with the second of the three distinct types of deposit exhibited by the Mesozoic rocks of Central Peru. This is the so-called 'volcanic facies,' and consists chiefly of beds of porphyritic agglomerate, though in places these are associated with more normal types of deposit such as limestones and quartzites. It is almost entirely confined to the western slopes of the Cordillera, and in view of the evidence obtained in the district of Cajamarca, farther north, its age is thought to be not earlier than the Cenomanian.

Later intrusions of andesite and dacite, probably of Tertiary age, are also of common occurrence in this district, though all trace of recent volcanic activity is wanting.

The underlying granodiorite core, although not actually exposed at this altitude along the line of section, must be very near the surface, for it comes to light close at hand in the Morococha Valley, where it is associated with a large laccolitic intrusion of dacite. Its outcrop is here nearly 16,000 feet above sea-level, and it thus plays a very important part in the construction of the Cordillera.

After crossing the summit of the range near Ticlio, we encounter a third zone of Mesozoic rocks, consisting for the greater part of limestones, in many places richly fossiliferous. The beds are everywhere strongly folded, and frequently show vertical and reversed dips. Palæontological evidence tends to indicate the presence of a great break in the geological sequence, beds of Liassic age being found in close proximity to those containing a fauna characteristic of the Albian, while deposits that should normally intervene appear to be entirely wanting. These fossiliferous limestones probably extend into the Cenomanian, but no evidence was obtained of the existence in the district of beds of later age than this.

Mesozoic rocks are continued down the eastern slopes of the Cordillera as far as Tarma, where they rest unconformably on strongly-folded rocks of Palæozoic age. Owing to the almost complete absence of fossils in the latter, however, it is impossible for the present to assign them to any definite geological formation. Limestones thought to be of Carboniferous age are found near Palca and again below Utcuyacu; but, for the greater part, the rocks consist of metamorphosed phyllites and mica-schists penetrated by a granite which has also shared in the dynamic crushing

and has been in places converted into a banded gneiss. At San Ramon a further great mass of plutonic rock is met with, which was proved to extend for some distance beyond the eastern limit of the section. This is essentially a rock of 'Atlantic' facies, as distinct from the 'Pacific' types which alone are displayed in the Cordillera. It is suggested that the origin of this Perene granite, like that of a similar rock occurring in the coastal Cordillera of the south, dates from a very early period antecedent to the uplift of the Andes.

In conclusion, a brief synopsis may be given of the general distribution of the rocks which build up the Cordilleras in this part of South America, as shown in this and two other parallel sections previously described by me. The earliest rocks are met with in the fragments of a coastal Cordillera which fringe the Pacific coast in Southern Peru, between Mollendo and Pisco. These consist of ancient crystalline gneisses and associated plutonic rocks. The latter are of alkaline facies, and are quite distinct from the calcic types which everywhere characterize the development of igneous activity in the main Cordilleras. They thus belong to what may be regarded as a definite extra-Andean igneous province, dating possibly from Archæan times.

If we now make a complete traverse of the Cordilleras, we again meet with rocks of similar character cropping out along the foot of the eastern slopes, in the forested region drained by the headwaters of the Amazon. Thus, for example, in the Perene district of Central Peru, we find an ancient granite closely resembling that which occurs on the coast at Mollendo; while farther south in the Inambari region, elæolite-syenites are the dominant type. The latter are probably of early Palæozoic age.

The later transgressive deposits, which form the bulk of the folded chains, are thought to have been laid down in a geosyncline bounded by two resistant horsts, composed largely of these ancient plutonic rocks, between which they have been compressed and elevated to the position that they occupy at the present day. This compression, however, has been of intermittent character, periods of uplift, characterized by folding and erosion, having alternated with periods of submergence, characterized by renewed deposition. Moreover, the compression has not everywhere been of the same magnitude. Where it has been greatest, as shown by a diminution in the breadth of the Cordillera, there, as might be expected, the folding has reached the greatest degree of complexity. Where it has been least, there gentle anticlines and synclines are the rule. Again, it has probably not been uniform in point of time throughout the length of the Cordillera.

This is suggested by the lithological change exhibited by certain formations when they are traced from south to north. Thus, the typical shallow-water type of Cretaceous deposits in Southern Peru, characterized by the predominance of red sandstones and marls with abundant seams of gypsum and rock-salt, is replaced

towards the north by a limestone facies that has clearly been laid down under true marine conditions. Evidence of a somewhat similar nature may also be cited from the Jurassic rocks. In Central Peru no younger beds than the Lower Lias were met with; farther south at Lagunillas on the Arequipa-Puno railway deposits of Inferior Oolite age are found, while at the Morro de Arica in the extreme north of Chile the series is continued into the Oxfordian. Although this distribution might be partly accounted for as a result of pre-Cretaceous erosion, in my opinion it is largely due to differential uplift which in this case commenced earlier in the north than in the south.

Turning now to the actual sequence of deposits, we find that Palæozoic sediments older than the Devonian are everywhere confined to the eastern flanks of the Andes. Fossils are of rare occurrence in these rocks, and no attempt has up to the present been made to establish their detailed subdivision. A definite belt of Ordovician graptolite-bearing shales (of Llanvirn age) appears, however, to be more or less continuous from Bolivia to the Inambari district in Peru. Farther north these beds are possibly represented by the altered phyllites described in the foregoing paper.

Fossiliferous deposits of Lower and Middle Devonian age are of wide extent in the region of Lake Titicaca and the Bolivian Altaplanicie. Their extension north of Cuzco is unknown, but they appear to be wanting in the Chanchomayo district of Central Peru.

Owing to the absence of Upper Devonian and Lower Carboniferous rocks over the whole of the country, a period of orogenic uplift appears to have set in at this time, the uplift being probably accompanied by the intrusion of the granite of the Eastern Cordillera of Bolivia. Both the syenitic rocks of the Inambari area and the granite of Utcuyacu described above, though possibly of earlier date, may also have had their origin at this time. All these rocks show evidence of subsequent dynamic metamorphism. This feature, however, cannot be explained solely by their age, for younger rocks have shared with them compression and folding, possibly of even greater magnitude than that of the earlier movement, with but little alteration.

Their position with reference to the general trend-lines of the Cordillera must also have been a determining factor: for it is a significant fact that, almost without exception, the metamorphic rocks are confined to the margins of the folded chains away from the axis of major uplift. Here, situated close to the resistant horsts which form the 'jaws of the vice,' they have been exposed, without experiencing the relief obtained by uplift, to the full force of the compression. Lower Carboniferous rocks have been recorded only at Viscachani, between Tirapata and Ollachea, where I discovered a fauna indicative of the extreme top of the Avonian sequence. They possibly also occur in the Palca district of Central Peru, but definite proof of their existence has not yet been established.

In Southern Peru the succession of marine deposits recommences with rocks of Upper Carboniferous or Permo-Carboniferous age. These are best known from the region of Lake Titicaca, where they are well-exposed on the Isthmus of Copacabana and the Island of the Sun. The existence of a land-area on the west is indicated by the occurrence of beds containing a flora characteristic of the Coal Measures, on the peninsula of Paracas, south of the port of Pisco. This is the only known record of fossiliferous Palæozoic rocks along the whole coast of Peru.

Of early Mesozoic deposits in the South of Peru little appears to be known, and I nowhere encountered beds of Triassic age. Jurassic deposits, however, are of wide extent, and in the south of the country they form the foundation on which are situated the giant volcanic cones of the Western Cordillera.

Beds of Callovian and Oxfordian age are exposed along the coast at Arica. Elsewhere they are largely concealed by Tertiary and recent volcanic material, and crop out only along the river-valleys. In the latitude of Arequipa, beds of Inferior Oolite age are clearly seen to have been folded and eroded before the deposition of the overlying transgressive Cretaceous deposits. In Central Peru, however, owing to the intensity of the subsequent Tertiary folding, this post-Jurassic unlift is not so clearly displayed. Fossiliferous Liassic deposits are here of common occurrence, but no Middle or Upper Jurassic rocks were encountered.

The post-Jurassic uplift was accompanied by deep-seated intrusion, for numerous derived pebbles of plutonic origin were found in the basement conglomerate of the Cretaceous sequence. During Cretaceous times a wide marine transgression took place, and fossiliferous limestones chiefly of Albian and Cenomanian age are the dominant feature of the Cordillera in Central Peru.

When followed southwards these are seen to be replaced by red gypsiferous sandstones and marls, very similar in appearance to our British Triassic deposits, and obviously laid down under much the same conditions, communication with the open sea having probably been cut off by an accumulation of volcanic material. Volcanic activity had already broken out in Upper Jurassic times, as shown by the interbedded pillow-lavas of the Morro de Arica. It was renewed with increased vigour towards the close of the Cretaceous Period, when vast accumulations of pyroclastic material (the so-called 'porphyritic conglomerate') were the chief product, and has continued, more or less without interruption, in the south of the country down to the present day. Here recent volcanic cones, many of them rising over 19,000 feet above sea-level, form the dominant feature of the Western Cordillera.

In Central Peru, although there is abundant proof of post-Cretaceous volcanic activity, recent volcanoes are completely wanting. Evidence of deep-seated intrusion is, for this reason, even better displayed here than in the south, where a thick mantle of lava and tuff, in places as much as 12,000 feet thick, obscures the underlying rocks.

This plutonic intrusion, which had its initiation during the post-Jurassic uplift, probably occurred for the greater part during the Tertiary folding of the Andes, when it took the form of a great batholithic invasion of the Cretaceous and older rocks, preceded by and intimately connected with a phase of volcanic eruption. At the present day an extensive mass of granodiorite, varying but little in character wherever it is exposed, forms a continuous core throughout the whole of the Andes of Central and Southern Peru, over a distance of more than 750 miles, and this must be merely a fragment of its total extent. The subsequent history of the Cordillera down to the period of human existence comprises many interesting geological problems, the detailed discussion of which was beyond the scope of the foregoing paper. Recent movements of the strand-line, the former extent of glaciation, and the origin of Lake Titicaca, are among those that call for further investigation.

In conclusion, I feel that, as a visitor to the country about which I have written, I must bear witness to the excellent work accomplished by the rapidly-growing school of geologists in Lima, from whom, and especially from their leader Prof. C. I. Lisson, I plead for lenient criticism. The geology of this vastly-interesting country is as yet very imperfectly known. Many difficult problems remain to be solved, and many errors committed by foreign writers, which are the inevitable accompaniment of rapidly-constructed surveys of this nature, stand in need of correction.

If, however, this series of papers, published as the result of my travels through Peru, acts in any way as an incentive to further work, even though this may lead to contradiction of many of my views, I shall feel that, apart from the great gain of personal experience, the late Mr. Balston's generosity in defraying the cost of the expedition has in part been repaid.

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EXPLANATION OF PLATES XV–XX.

PLATE XV.

Figs. 1 *a* & 1 *b*. *Terebratula* (*Lobothyris*) cf. *ovatissima* Quenstedt (obese variety). Lower Lias. Charata, near Oroya, Peru. (Natural size; see p. 264.)

Fig. 2. Do. do. (elongate variety). Lower Lias. Charata, near Oroya, Peru. (Natural size; see p. 265.)

3. Do. do. Anterior view, showing 'rectimarginate' stage of growth. (Natural size.)

4. Do. do. Anterior view, showing 'uniplicate' stage of growth. (Natural size.)

Figs. 5 & 6. Do. do. Anterior views, showing 'sulciplicate' stage of growth. (Natural size.)

Fig. 7. *Trigonia lorentii* Dana. Neocomian. Isle of San Lorenzo, Callao, Peru. (Natural size; see p. 253.)

Figs. 8 *a* & 8 *b*. *Schlœnbachia ventanillensis* (Gabb). Albian. Saco, near Oroya, Peru. (Natural size; see p. 270.) Young form, showing transition from smooth to costate stage.

PLATE XVI.

Fig. 1. *Schlœnbachia* sp. (cf. *acutocarinata* [Shumard] Böse). Albian. Saco, near Oroya, Peru. ($\times \frac{3}{4}$; see p. 269.) Specimen showing ribbing of cast.

2. *Schlœnbachia multifida* Steinmann. Albian. Saco, near Oroya, Peru. (Natural size; see p. 267.) Specimen showing the nature of the ribbing in the cast of a young individual, and smooth shell preserved on the inner whorls.

3. Do. do. ($\times \frac{1}{2}$.) Mature individual with shell preserved, except near the mouth.

4. Do. do. (Natural size.) A portion of the same individual, showing the true nature of the ribbing on the shell.

5. Do. do. (Natural size.) Peripheral view of a young individual.

PLATE XVII.

Fig. 1. *Schlœnbachia* cf. *belknapi* (Marcou) Böse. Albian. Saco, near Oroya, Peru. (Natural size; see p. 269.) Portion of a cast of a large individual.

2. *Schlœnbachia* sp. Albian. Saco, near Oroya, Peru. (Natural size; see p. 270.) Probably a young example of *Schl. belknapi*.

3. *Schlœnbachia* sp. (cf. *Schl. chihuahuensis* Böse). Albian. Yauli, Peru. (Natural size; see p. 269.)

4. *Schlœnbachia ventanillensis* (Gabb). Albian. Saco, near Oroya, Peru. (Natural size; see p. 270.) Specimen showing adult type of ornamentation.

PLATE XVIII.

View of the upper part of the Morococha Valley, showing the Anticona laccolite and Lake Huacracocha. (See p. 261.)

PLATE XIX.

Upper part of the Anticona laccolite, showing dacite capped by Cretaceous limestone. (See p. 261.)

PLATE XX.

Geological section through the Andes from Callao to the Perene River. Scales: horizontal, 1 : 400,000; vertical, 1 : 100,000. *For* 'Oyora,' *read* 'Oroya.'

DISCUSSION.

Dr. J. W. EVANS said that the paper was a valuable contribution to our knowledge of the geology of Peru. The comparison between the geology of this section across the Andes with those previously described was full of interest. He suggested that the change of strike from roughly north-west towards north-north-west was not without significance. Ultimately, still farther north, the strike became north and south. In a paper on the rocks of the Madeira Falls the speaker had contended that the lines of folding in South America with a north-west and south-east direction were older than those striking north and south, and this view was consistent with the facts adduced by the Author of the paper just read.

Prof. W. J. SOLLAS complimented the Author on a brilliant termination to his long-continued labours. The end worthily crowned the work. It was pleasing to contrast the circumstances in which the Author, in polished and easily-flowing language, had so lucidly expounded his results, surrounded with friends and all the comforts of civilization, with the laborious, often painful, and sometimes perilous adventures which had attended his wanderings among the desert plains and high mountains.

The Author had wisely abstained from entering upon hypothesis, but it would be interesting if he could let his auditors see a little deeper into his mind, and inform them as to what he thought about the mechanism of mountain-building. In such a lofty range one might well have expected mighty overthrusts, some plains of 'Piedmont' overriding the 'high Alps,' but we were told of nothing

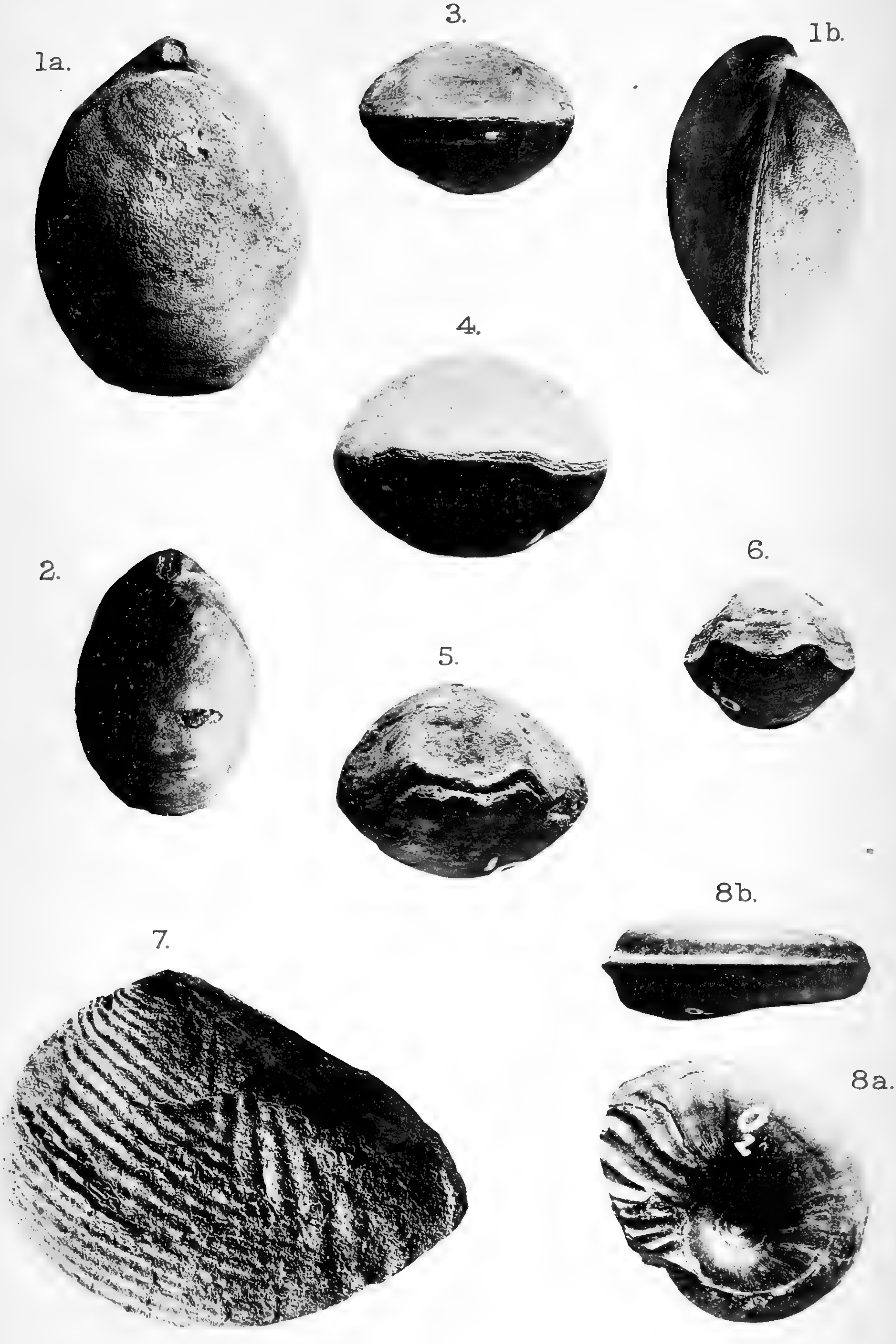
worse than strata vertically upreared on end and some overfolds. The igneous intrusions were, however, on a grand scale, and it looked as though it might be necessary to make a partial return to hypotheses now out of date. Possibly batholiths may have played a more important part than the opinions at present fashionable will concede.

The AUTHOR said that, in the short time at his disposal, he had only been able to give a very brief sketch of the geological features of the section, and several of the points raised by the speakers were dealt with more fully in the paper. He fully agreed with Dr. Evans that much of the evidence tended to show that the folding was not contemporaneous throughout the length of the chain. In the Jurassic rocks, for example, deposition appeared to have ceased with the Lower Lias in the district now described; farther south it was continued into Bajocian times, while in the north of Chile beds of Oxfordian age were found. The transition of the fossiliferous Cretaceous limestones of the north into the gypsiferous red sandstones of the south was also a significant feature.

In reply to Prof. Sollas, he said that the facts now recorded were in no way opposed to the views that he had previously expressed, as to the nature of the processes which gave rise to the uplift of the Andes. The great granite-mass of the Perene formed, with the nepheline-syenites of the Inambari district, one of the jaws of the vice that had compressed the transgressive deposits of the geosyncline. Fragments of the other jaw were to be found in the similar granite of the coastal Cordillera.

In conclusion, he reminded the Fellows of the debt of gratitude which he owed to the late Mr. W. E. Balston, who had enabled him to visit South America, and at the same time thanked them for the kind reception given to his paper.

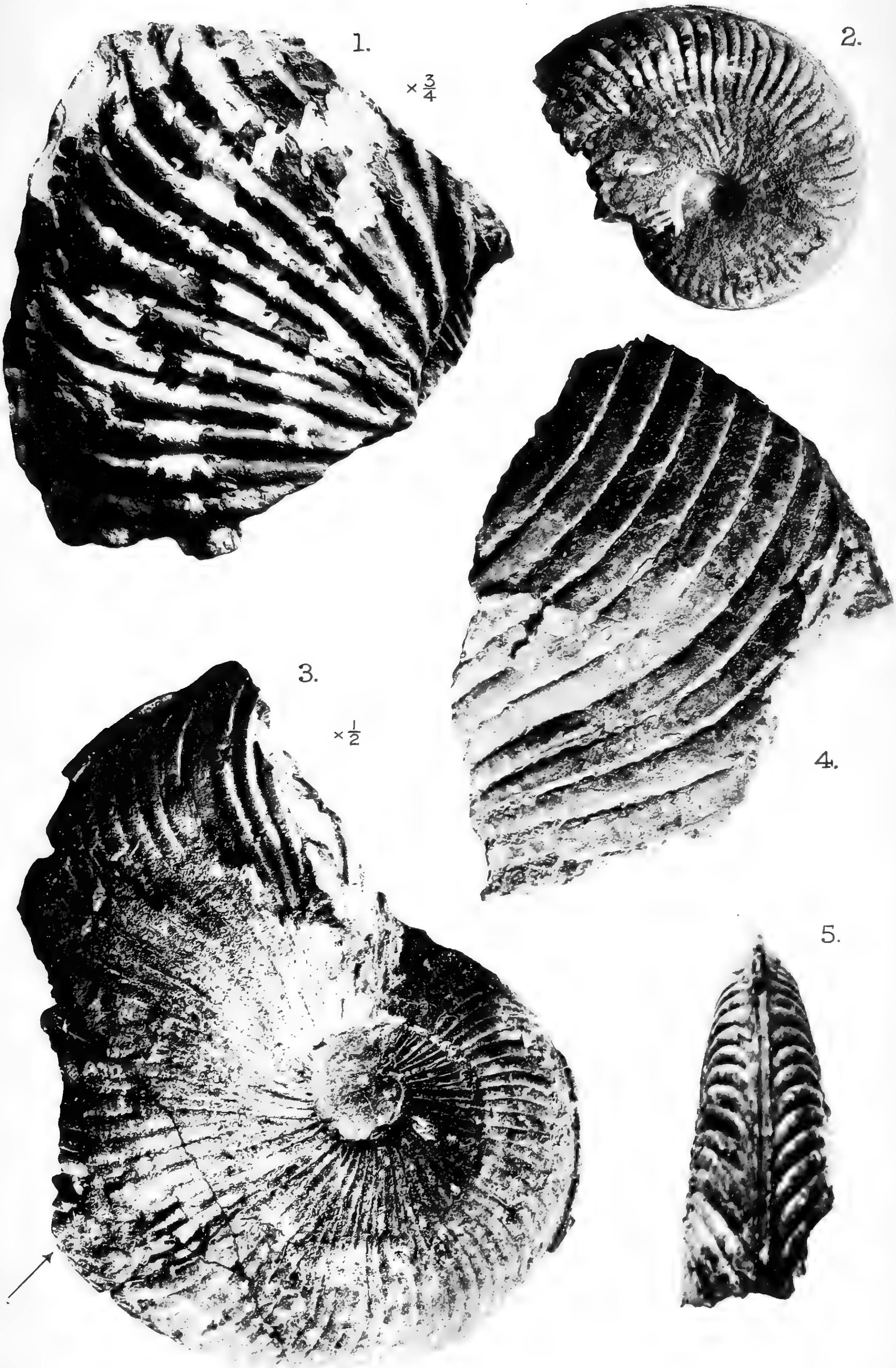
[**November 11th, 1921.**]



J.A.D., Photo.

Bemrose, Collo., Derby.

FOSSILS FROM THE ANDES (CALLAO-PERENE SECTION).



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FOSSILS FROM THE ANDES (CALLAO–PERENE SECTION).

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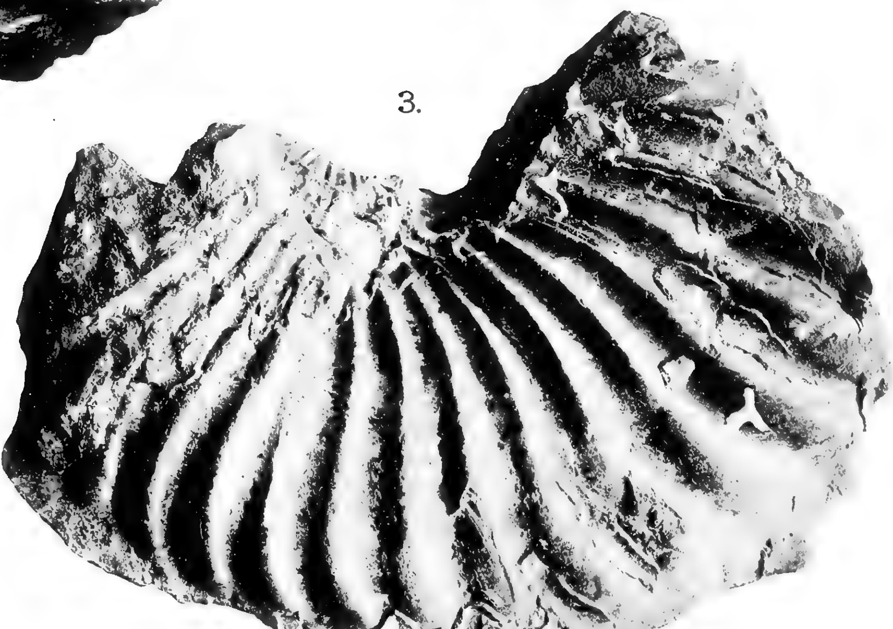
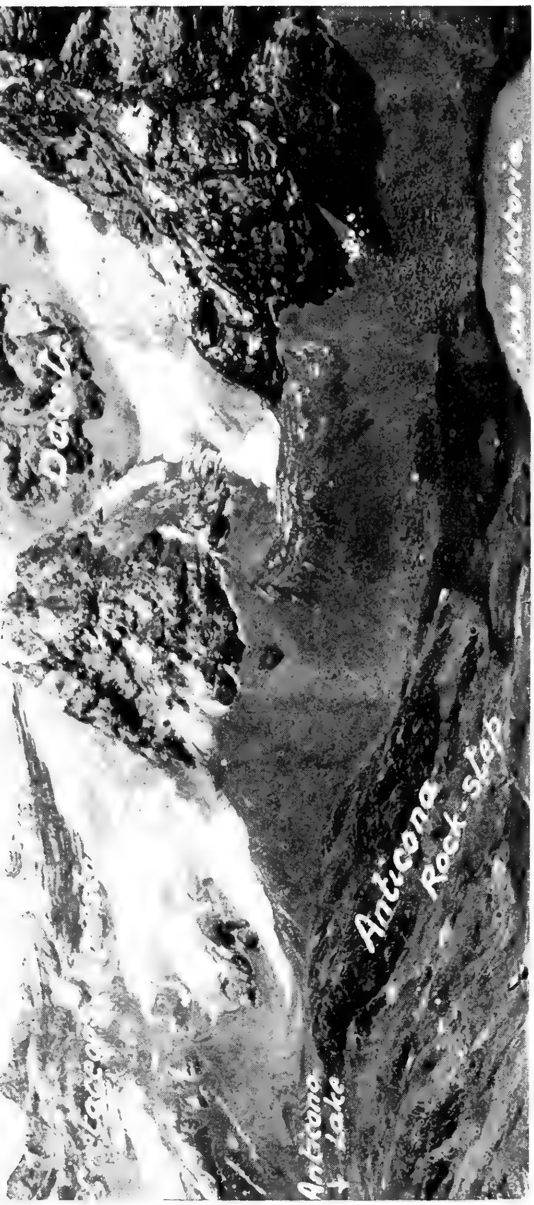


J.A.D., Photo.

Bemrose, Collo., Derby.

FOSSILS FROM THE ANDES (CALLAO-PERENE SECTION).

View of the Upper Part of the Morococha Valley, showing the Anticona Laccolite and Lake Huacracocha.



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Session 1921–1922.

1922.

Wednesday,	January	4*—18*
„	February (*Anniversary Meeting*, Friday, February 17th)	1*—22*
„	March	8 —22*
„	April	12
„	May	10*—24
„	June	14*—28

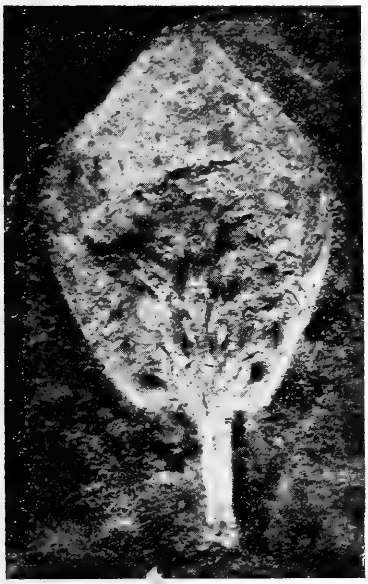
[*Business will commence at 5.30 p.m. precisely.*]

The asterisks denote the dates on which the Council will meet.

12. *An* OTTOKARIA-LIKE PLANT *from* SOUTH AFRICA. By HUGH HAMSHAW THOMAS, M.A., F.G.S. (Read May 4th, 1921.)

IN the Karharbari Beds (Lower Gondwana) of Passerabhia (India), a very curious and characteristic fossil was found, to which the name of *Ottokaria bengalensis* was given by Zeiller. It is of interest, not only owing to its unusual form and problematical nature, but also on account of its association with *Glossopteris indica* and our uncertainty as to the reproductive structures of this form. Although leaves nearly allied to *G. indica* have been found in a large number of localities, not only in India but in Australia, South Africa, and Russia, fossils of the *Ottokaria* type are very rare, and, in addition to the Indian specimen, only one other example (from Brazil) has been described. The object of this note is to record the discovery in South Africa of a fossil which seems to be closely allied to, if not actually referable to, the genus *Ottokaria.*

Fig. 1.—*Photograph of* Ottokaria Leslii, *sp. nov. Natural size.*



The specimen (illustrated in fig. 1) was sent by Mr. T. N. Leslie, F.G.S., to Prof. A. C. Seward in 1913, and was recently handed to me for investigation. It occurs as an impression in a rather coarse-grained sandstone, and was derived from the Vereeniging Sandstones of the Transvaal.

The original description and figures of *Ottokaria* by Zeiller [1] were published in 1902, and the specimen was recently refigured and described by Seward & Sahni in their revision of the Indian Gondwana plants,[2] to which there is nothing further to add. The Brazilian specimen described by David White [3] was called *Ottokaria ovalis* White, and was almost identical in size with the head of the present example. Its upper portion was broken away, and it may possibly have possessed a form similar to that described below,

[1] 'Observations sur quelques Plantes Fossiles des Lower Gondwanas' Palæontologia Indica, n. s. vol. ii, No. 1 (1902) p. 34 & pl. iv, figs. 9–10.

[2] 'Indian Gondwana Plants: a Revision' *ibid.* vol. vii, No. 1 (1920) p. 12 & pl. ii, fig. 19.

[3] 'Fossil Flora of the Coal Measures of Brazil' in Final Report of I. C. White, pt. iii, Rio de Janeiro (1908) p. 533 & pl. vii, figs. 7–7 *a*.

although there is no mention by White of a part corresponding to the wing. Other points of comparison are also possible.

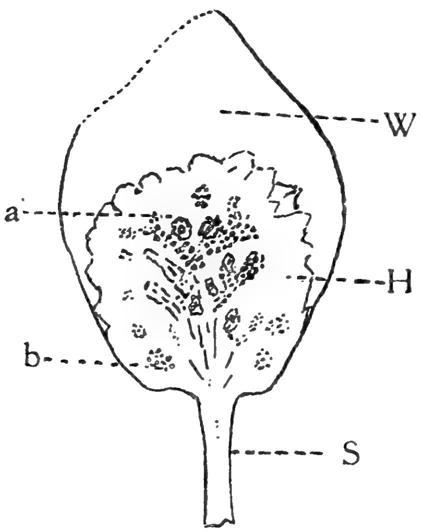
The specimen now described exhibits some important distinctions from the type, as will be seen by comparing the figures; it may, however, be regarded as showing a different stage in the development of the same organism, and, in the absence of a specimen showing better preservation, I do not think that anything is to be gained by erecting a new genus for its reception. I propose only to institute a new species, and shall therefore call the present specimen *Ottokaria Leslii*, after its discoverer.

OTTOKARIA.

OTTOKARIA LESLII, sp. nov.

The original type consisted of a more or less circular lamina seated on a long stalk, and the specimen now described shows an ovate structure borne on a stalk. It is a little difficult to determine the morphological nature of the parts, and to be at all certain of the organs which gave rise to the impression here described. This is partly on account of somewhat bad preservation, but more especially because of our ignorance of any similarly-shaped organ in living plants.

Fig. 2.—*Diagram indicating stalk* (S), *head* (H), *and wing* (W).



[*a*=scars of appendages?; *b*=patches of brown cells.]

The fossil now described may be termed an impression, but the remains of part of the plant-tissue are still left. Three regions may be distinguished:—(1) the stalk; (2) the thickened circular portion or head, with forking ribs of brown cells; and (3) the thin apical zone or wing. The first and second regions may be compared in a general way with Zeiller's *Ottokaria*; but the third region has no counterpart in the type-specimen of the genus.

Of the stalk only about 15 mm. is seen; it has a uniform width of about 4 mm., and expands gradually into the head. Most of the tissue appears to have become converted into a white structureless substance. In the centre of the stalk, however, a small streak of brownish material is seen, and this may be compared with the brown ridges to be mentioned later. It was probably formed from the harder tissues of the vascular strand.

The second region, which may be designated by the non-committal term of the head, shows several curious features. It is almost

circular, but slightly auriculate at the base, and has a diameter of about 20 mm. Its outlines are not sharply demarcated, and the surface-characters are not like those of the Indian specimen. It would appear as though the original surface had been removed. On the other hand, we see a series of slightly raised humps of brownish material, often connected by ribs of the same substance, which seem to have formed part of a system spreading and forking from the point of attachment of the stalk. In one or two places these ridges appear to terminate in irregular masses suggesting the scars of appendages produced at right angles to the plane of our specimen. If the brown ridges are examined with a binocular microscope, they show in several places clear indications of a cellular structure, the cells being small and rectangular in shape, and suggesting the original presence of thickened strengthening tissue. These indications of a spreading system of ridges are comparable with the surface appearance of the type *Ottokaria*; but in that case they were much closer, smaller, and more numerous.

The edge of the head is quite indefinite; but, as seen under the binocular microscope with oblique light, there are indications of a series of dentate projections, again fewer in number and larger in size than in the Indian example, though suggestive of a comparison. These projections are very indistinct, and may perhaps be only accidents of preservation.

The third region may be termed the wing, this word being used without prejudice to the nature and origin of the structure so designated. It arises towards the lower part of the head, and expands gradually to a width of 3 cm. as measured transversely near the top of the head; it then narrows, but its entire apical portion is not seen, owing to the fracture of the matrix at a distance of 2 cm. from the head. The 'wing' thus presents an elliptical or slightly ovate shape, with an entire margin.

While the head appears as though formed from a more or less solid, perhaps spherical body, the wing presents the appearance of formation from a thin or flattened structure. A good deal of the original plant-tissue is again represented by a white amorphous substance with a smooth surface; but in several places this has disappeared. There is no sharp line of demarcation between the wing and the head: in some places the white altered tissue of the wing appears to extend over the head, in other places the head seems to be delimited by a crack, though the substance on each side of the crack appears very similar.

There are no clear indications of the original nature of any of these structures save the stalk, nor of their morphological category. There can be little doubt of the vegetable origin of the fossil, and it seems highly probable that it was connected with the reproduction of the plant on which it grew. Until further specimens are available, I think that we may regard the head as a kind of woody cupule in which a seed or seeds were produced; and it is quite possible that the structure here called the 'wing' was a large

platyspermic seed, originally produced in the cupule, but growing out beyond it as it approaches maturity.

On this view the Indian *Ottokaria* would be regarded as a similar structure, in which the seed had not yet matured. It seems difficult, however, to press this interpretation, in view of the absence of a clear line of demarcation between the head and the wing, although it is conceivable that in the process of preservation this demarcation may have become obliterated.

David White records the presence of small oval bodies 1 to 1·25 mm. long and 5 mm. (? misprint for ·5 mm.) wide on the surface of his specimen:—'in some cases a small round or oval point was indistinctly seen a little above the middle of these impressions,' and 'the distal ends were a little wider.'

These bodies were regarded as sporangia; but no spores were obtained from them. It is my opinion that the bodies so described may have originated from the same structures as those that formed the projections and humps of brown cells seen on the surface of the specimen now described, though little comparison is useful with White's figure (pl. vii, fig. 7 *a*). I think that there can be hardly any doubt that the projecting humps which I have described were not sporangia, but rather of the nature of ornamentations, and similar to the marginal projections seen in the Indian and Brazilian specimens.

Another explanation of the original nature of the wing presents itself, owing to the continuity of the white material (altered plant-tissue) from the wing to the head. This is the suggestion that the wing was originally formed from a thin elliptical envelope which ensheathed the head or cupule in this species, but was absent in the Indian form. This thin sheath may have sprung from the base of the head, and have extended some distance beyond it; when being flattened in preservation, it would assume the shape now possessed by the wing. On this view the head may itself have been a seed with a hard ornamented coat.

There may be other possible interpretations; but, until further specimens are discovered, no hypothesis can be adduced which has a very firm foundation. The suggested connexion with *Glossopteris* is also very speculative; so long, however, as the reproductive structures of that plant remain unknown, the association of *Ottokaria* with it in widely-separated localities is a fact which must be kept in view.

13. *On* NUMMULOSPERMUM, gen. nov., *the* PROBABLE MEGASPORANGIUM *of* GLOSSOPTERIS. By A. B. WALKOM, D.Sc. (Communicated by Prof. A. C. SEWARD, Sc.D., F.R.S., F.G.S. Read May 4th, 1921.)

[PLATE XXI.]

AMONG the fossil plants of Permo-Carboniferous age in the collections of the Queensland Geological Survey, it was my good fortune to find the specimens which form the subject of this communication. The results of the examination of the whole flora are being published by the Queensland Geological Survey as a continuation of my studies of the Queensland fossil floras. As, however, the specimens above mentioned represent, if my interpretation of them is correct, a very important discovery in fossil botany, it was thought that the subject merited a separate communication. In doing this I hope that the attention of palæobotanists may once more be drawn to the subject of the systematic position of *Glossopteris*, and that the evidence here brought forward may be critically considered in its bearing on this problem.

From time to time there have been suggestions that specimens of *Glossopteris* have been found showing structures regarded as sori, but in no case has anything definite been proved in this direction. As regards Australian specimens. these suggestions date back to 1872, when William Carruthers, in describing *G. Browniana* collected by Daintree from Queensland, said:

'..... one shows some indications of fruit in the form of linear sori running along the veins, and occupying a position somewhat nearer to the margin of the frond than to the midrib.' (Bibliography, No. 3, p. 354.)

In 1905 perhaps the first definite step was taken towards the solution of the problem of the systematic position of this plant, in Arber's discovery of small bodies attached to the scale-leaves of *Glossopteris*, which he described as probable microsporangia (Bibliography, No. 1, p. 324; No. 2, p. 41). Then, in 1908, David White noted the intimate association, in Brazil, of seeds of the *Samaropsis* type with *Gangamopteris* (Bibliography, No. 8, p. 559), and went so far as to state his belief that the seeds were those of *Gangamopteris*, referring to them as *Gangamopteris (Samaropsis) Seixasi*, sp. nov. Prof. Seward (Bibliography, No. 7, p. 354) suggests also that *Samaropsis Milleri*, a species occurring in the Karharbari Beds in India, may be the seed of a species of *Glossopteris*, one specimen occurring partly covered by a scale-leaf of a type very similar to that generally recognized as belonging to *Glossopteris*.

These are, so far as I know, the most important contributions hitherto made towards the elucidation of the real nature of *Glossopteris* and *Gangamopteris*.

A detailed description is appended of the Queensland seeds, for which the new genus *Nummulospermum* is proposed, and this is followed by a discussion of the grounds on which their connexion with *Glossopteris* is based.

NUMMULOSPERMUM, gen. nov.

This name is proposed for a number of seeds occurring in association with *Glossopteris* at Three-Mile Creek, Bowen. Three-Mile Creek is a small tributary of Pelican Creek, which is a branch of the Bowen River. The question of their occurrence and association is discussed below.

Seed platyspermic (?); circular or oval, with broadly acute apex. Integument consisting of wide outer sarcotesta and (?) narrow inner sclerotesta. Nucellus circular, with prominent beak projecting into the narrow micropyle. Vascular system consisting of a single strand entering the base, giving off a pair of strands in the sarcotesta, then passing through the sclerotesta and (?) dividing into a number of strands enveloping the megaspore, and extending nearly to its apex.

Genotype: *Nummulospermum bowenense*, sp. nov.

The foregoing description summarizes what appear to be the essential characters of these seeds, which are discussed more fully below under *N. bowenense*.

The characters of the seeds seem to be sufficiently well indicated to warrant some more distinctive name than *Samaropsis*, and at the same time the structure does not conform to that of any of the described fossil genera known to me.

NUMMULOSPERMUM BOWENENSE, sp. nov. (Pl. XXI, figs. 1–4, & text-fig., p. 291.)

Characters as described for the genus.

Type: F 1900 in the collection of the Queensland Geological Survey, from Three-Mile Creek, a tributary of Pelican Creek.

On a large specimen (F 1900) from Three-Mile Creek, Bowen (Pl. XXI, fig. 1), there are remains of at least twenty-eight of these seeds, and all of them present the same view of the seed. From their general appearance, and the fact that all the seeds known are preserved showing the same aspect, one might reasonably conclude that the seeds were platyspermic, and had split along a principal plane. We must remember, however, that in several of its characters the genus *Nummulospermum* shows close affinities with members of the Trigonocarpales, in which the seeds are radially symmetrical (Radiosperms).

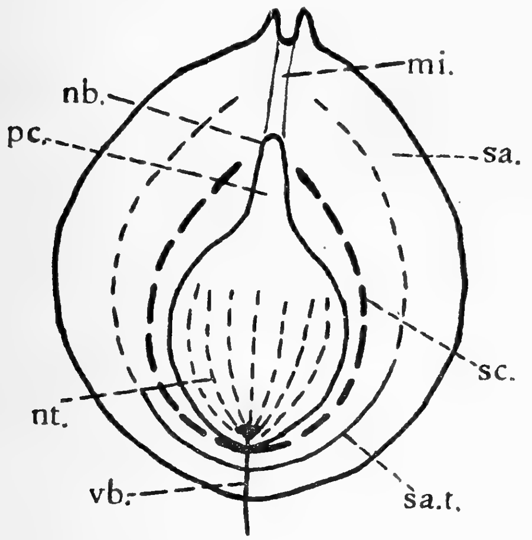
The impressions as preserved appear to represent the features of the seeds as seen on a principal plane, along which they apparently

split readily. They are approximately circular, or oval, with a broadly acute apex, in which, in some cases, there is a marked depression (Pl. XXI, fig. 3). The length of the impression varies from 9 to 11 mm., and the breadth from 8 to 11 mm.

The sarcotesta is well-developed, and is much wider in the lateral and apical regions than in the basal portion, where it becomes comparatively narrow. Near the apex it varies from 3 to 5 mm. in thickness, while near the base it is not more than 1 mm. thick.

Very little definite indication can be obtained from the specimens regarding the nature of the sclerotesta. In some of them there is a suggestion of a distinct narrow layer immediately outside the nucellus (Pl. XXI, fig. 4, *sc*), and this may indicate a thin inner sclerotesta, outside which there is the thick sarcotesta. There would appear to be no inner layer of sarcotesta, as is the case in some such seeds.

Diagrammatic restoration of Nummulospermum bowenense, *gen. et sp. nov.*



Section through principal plane (× 4). *mi*=micropyle; *nb*=nucellar beak; *nt*=nucellar bundles; *pc*=pollen-chamber; *sa*=sarcotesta; *sa.t.*=bundles in the sarcotesta; *sc*=sclerotesta; *vb*=vascular bundle entering the base of the seed. The degree of attachment between nucellus and sclerotesta cannot be determined from the specimens.

The nucellus is circular in the principal plane, its diameter being about 6 mm., with a distinct nucellar beak up to 2 mm. long and somewhat less than 1 mm. broad. This nucellar beak would contain the pollen-chamber, which would appear to be of comparatively large size. In some of the specimens it is obvious that the nucellar beak is placed opposite the narrow micropyle leading to the apex of the seed.

In general shape the nucellus resembles that of *Stephanospermum akenioides*, as figured by Coulter & Chamberlain (Bibliography, No. 4, p. 43, fig. 45), and of *Trigonocarpum Parkinsonii* (*ibid.* p. 44, fig. 46), both of which are Radiosperms. The nucellar region in a number of examples is occupied by a dark, somewhat vesicular-looking mass; but this does not show any preservation of structure when examined under the microscope.

As in many fossil seeds, the preservation of details is not sufficiently good to enable one to determine to what extent the nucellus may have been free from the integument.

There are indications, in some of the examples, of the nature of the vascular system. In one or two specimens there is a distinct ridge running from the base of the seed to the base of the nucellus (Pl. XXI, fig. 2). This ridge gives off a pair of ridges, one on each side, into the sarcotesta, and these two ridges continue for some distance parallel to the junction between nucellus and integument. This seems to be a plain indication of a single vascular bundle entering the base of the seed, giving off a pair of bundles running through the sarcotesta in the principal plane of the seed. It cannot at present be determined how far this pair of bundles extends towards the apex of the seed; but it is not improbable that they will be found to extend almost, if not quite, to the micropyle. Further, in some specimens, the body of the nucellus shows a number of distinct vertical ridges; it is not unlikely that these represent a series of distinct strands arising from an expansion of the main bundle where it reaches the base of the nucellus, as is the case in *Cardiocarpus* (see Oliver, Bibliography, No. 5, pl. xxiv, fig. 1), and in some Radiosperms. These ridges extend almost to the upper margin of the circular portion of the nucellus (that is, excluding the nucellar beak).

The specimens exhibit very little variation in size, and it may reasonably be concluded that they represent the dimensions of the mature seed; their diameter is about 10 mm. in the principal plane of the seed. None of the specimens gives an idea of the thickness perpendicular to this plane.

Species associated with *Nummulospermum bowenense*.

A number of specimens have been collected from Three-Mile Creek, Bowen, and, in addition to the seeds just described, the only species observed from that locality are *Glossopteris indica*, *G. ampla*, and *G. Dunstani*, sp. nov. On the actual slab in which the seeds are preserved there are only examples of *G. ampla*. Apart from actual connexion of the seeds with *Glossopteris*, it would hardly be possible to obtain stronger evidence of close relation between them than this. But this is not quite all: the evidence is somewhat strengthened by the following occurrences among the Queensland collections:

(*a*) Near Pentland, a single seed (*Samaropsis Etheridgei*, sp. nov.) occurs on the same piece of rock as fronds of *Glossopteris indica*; the only other species noted from the same locality is *G. ampla*.

(*b*) From Minnie Creek, there is also a single seed, probably an example of *Nummulospermum bowenense*. It occurs in association with *Glossopteris Browniana*, *Sphenopteris lobifolia*, and scale-fronds of *G. Browniana*.

(*c*) From Barwon Park, there are three flattened seeds, also probably *N. bowenense*, occurring on the same specimen as *G. Browniana* and a *Sphenopteris*. The only other species from the same locality are *G. indica* and ? *G. tortuosa*.

Add to these David White's description (Bibliography, No. 8,

p. 559) of the association of seeds of somewhat similar type with *Gangamopteris* fronds in Brazil, and Prof. Seward's record of the association of *Samaropsis Milleri* with scale-leaves of the *Glossopteris* type; wherefore the evidence of association seems sufficiently strong to justify the statement that the seeds under discussion are those of a species of *Glossopteris*.

They would represent the megasporangia, the microsporangia having been discovered and described by Arber some fifteen years ago (Bibliography, No. 1, p. 324; No. 2, p. 41) on specimens from Port Stephens, New South Wales.

Of the Queensland localities mentioned above, Pentland is 148 miles west of Townsville on the railway-line; Three-Mile Creek is approximately 150 miles east of Pentland, and its position is roughly 147° 48′ long. E., 20° 35′ lat. S.; Barwon Park is on the Mackenzie River, and is about 180 miles south 25° east of Three-Mile Creek; Minnie Creek is about 30 miles south of Barwon Park, and 10 or 12 miles from Blackwater Railway-station, which is 125 miles from Rockhampton on the Central Railway.

From this it is seen that the localities at which these seeds are associated with *Glossopteris* are widely scattered, a fact tending rather to strengthen the evidence.

Scale-Fronds of *Glossopteris*.

It may be noted here that the scale-fronds occur in association with *Glossopteris* in Queensland. They cannot be distinguished from specimens figured by Zeiller from India (Bibliography, No. 9, pl. iii), and for comparison two of them are figured (Pl. XXI, figs. 5 & 6). There is no doubt that those resembling Pl. XXI, fig. 6, are in Queensland associated with *Glossopteris Browniana*; whereas in India both the types here figured are referred by Zeiller to *G. indica*. This goes to indicate that probably these two so-called 'species' really represent portions of one very variable species, Brongniart's original *G. Browniana*. Further details of these scale-fronds will be published with the full account of the Queensland Permo-Carboniferous flora mentioned above (p. 289).

Relationships of *Glossopteris*.

Although we have advanced a stage in our knowledge of *Glossopteris*, there is still much to be learned. The megasporangia show that the genus belongs either to the Cycadofilicales or to the Cordaitales, which two groups cannot be separated on the evidence of their seeds alone. If we take into account other features in connexion with *Glossopteris*, the balance of evidence appears to be in favour of its reference to the Cycadofilicales. The association of scale-fronds and perhaps the venation of the leaves support this; further, if we accept *Vertebraria* as being the underground rhizome of *Glossopteris*, the indication is that it belongs to the Cycadofilicales rather than to the Cordaitales. Parenthetically, it may be remarked that our knowledge of the fossil *Vertebraria* is

very far from complete, and we still lack a satisfactory explanation of its structure.

We have next to consider to which group of the Cycadofilicales the seeds described above as *Nummulospermum* belong. The vascular system is similar to that found in *Cardiocarpus* (a platyspermic seed belonging to the Cardiocarpales [1]), and also in some of the Trigonocarpales. *Nummulospermum* itself appears to be a platyspermic type of seed; it is distinguished from a number of the Upper Palæozoic Cardiocarpales (*Cyclospermum*, *Rhabdospermum*, *Cycadinocarpus*, and *Mitrospermum*) by the way in which the two vascular strands are given off from the main vascular strand entering the base of the seed before it reaches the sclerotesta (see B. Sahni, Bibliography, No. 6, fig. 7).

In the apparent possession of a large pollen-chamber, *Nummulospermum* shows a feature which is one of the characteristics of the Trigonocarpales.

The anatomical features then, so far as they can be made out with any degree of certainty, appear to favour the reference of this genus to the Trigonocarpales.

In conclusion, it is hoped that, as a result of this paper, renewed interest may be awakened in the possibility of proving or disproving the intimate association of seeds with *Glossopteris* in other areas where this widely-occurring genus is found.

I have once more to express my gratitude to Mr. B. Dunstan, F.G.S., Chief Government Geologist of Queensland, at whose suggestion I first undertook the study of the fossil floras of Queensland, and whose broad view of his subject is responsible for the comparatively large amount of palæontological work (palæozoology as well as palæobotany) that has been carried out in recent years on Queensland material. I have also to thank Prof. A. C. Seward for reading the proofs of this paper, and I may perhaps be permitted to express an appreciation of his kindly interest in my work at the other end of the world, an interest which has helped me over many difficulties, particularly in the earlier stages of my investigations.

Bibliography.

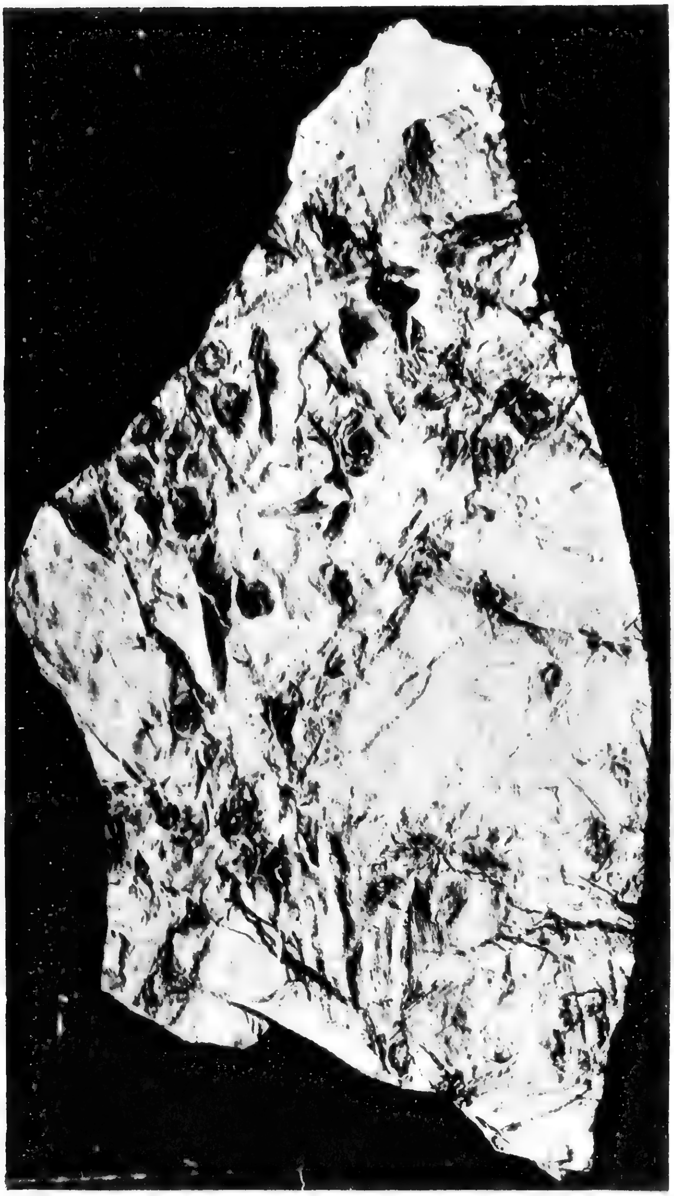
(1) E. A. N. Arber. 1905. 'On the Sporangium-like Organs of *Glossopteris Browniana* Brongn.' Q. J. G. S. vol. lxi, pp. 324–38 & pls. xxx–xxxi.

(2) E. A. N. Arber. 1905. 'The Fossil Plants of the *Glossopteris* Flora.' Catal. Brit. Mus.

(3) W. Carruthers. 1872. 'Notes on Fossil Plants from Queensland, Australia' Q. J. G. S. vol. xxviii, pp. 350–56.

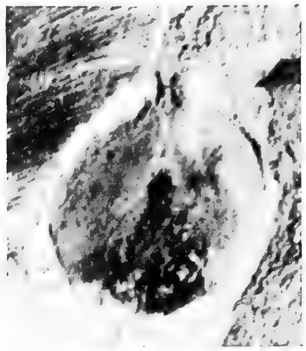
(4) J. M. Coulter & C. J. Chamberlain. 1917. 'Morphology of Gymnosperms.' Univ. of Chicago Press.

[1] Following Prof. A. C. Seward's (Bibliography, No. 7, pp. 307–308) subdivision of Palæozoic Gymnospermous seeds into Lagenostomales, Trigonocarpales, and Cardiocarpales.

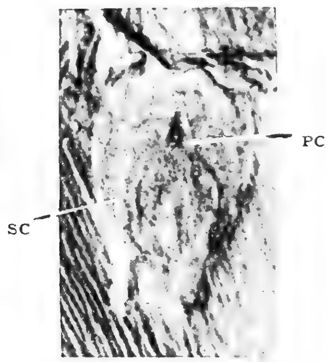


1 ($\times \frac{1}{2}$)

2 ($\times 2$)



3 ($\times 2$)



4 ($\times 2$)

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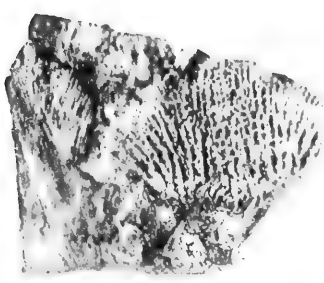


6

A.B.W. photo.

NUMMULOSPERMUM BOWENENSE, GEN. ET SP. NOV., AND SCALE-LEAVES OF GLOSSOPTERIS.

(5) F. W. OLIVER. 1903. 'The Ovules of the Older Gymnosperms' Ann. Bot. vol. xvii, pp. 451–76 & pl. xxiv.

(6) B. SAHNI. 1920. 'On certain Archaic Features in the Seed of *Taxus baccata*, with Remarks on the Antiquity of the Taxineæ' Ann. Bot. vol. xxxiv, pp. 117–33.

(7) A. C. SEWARD. 1917. 'Fossil Plants' vol. iii.

(8) D. WHITE. 1908. 'Fossil Flora of the Coal Measures of Brazil' in Final Report of Dr. I. C. White, Chief of the Brazilian Coal Commission, from July 1st, 1904, to May 31st, 1906, Part iii. Rio de Janeiro, 1908.

(9) R. ZEILLER. 1902. 'Observations sur quelques Plantes Fossiles des Lower Gondwanas' Mem. Geol. Surv. India (Pal. Indica), n. s. vol. ii, Mem. No. 1.

EXPLANATION OF PLATE XXI.

Fig. 1. Photograph of specimen showing *Nummulospermum bowenense*, sp. nov. and *Glossopteris ampla* from Three-Mile Creek, Bowen. (Half of the natural size.) Specimen F 1900.

2. *Nummulospermum bowenense*, sp. nov. (× 2.) At the base can be seen a vertical ridge giving off a curved ridge to the left in the sarcotesta. (These ridges show as light-coloured lines.) The dark central mass is sclerotesta *plus* nucellus. Traces of the micropyle can also be seen near the top. (See p. 292.)

3. *Nummulospermum bowenense*, sp. nov. (× 2.) Showing apex of seed with depression; also trace of micropyle from apex to nucellar beak. (See p. 291.)

4. *Nummulospermum bowenense*, sp. nov. (× 2.) Showing sclerotesta (*sc*) and pollen-chamber (*pc*), also traces of the vertical ridges on the nucellus which may represent vascular strands enveloping the nucellus. (See p. 291.)

5. Scale-leaf of *Glossopteris*, Dinner Creek, Stanwell. Specimen F 1888. (Natural size.) See p. 293.

6. Scale-leaf of *Glossopteris Browniana*, Dawson R. Specimen F 1895. (Natural size.) See p. 293.

DISCUSSION ON THE TWO FOREGOING PAPERS.

Mr. W. N. EDWARDS remarked on the desirability of finding in the *Glossopteris* flora either petrified specimens showing internal structure, or those possessing a cuticle which could be studied after chemical treatment, since conclusions based mainly on association must at present remain tentative.

Dr. A. M. DAVIES enquired as to the apparent resemblances between *Nummulospermum* and *Ottokaria*, and their relative size.

Dr. F. A. BATHER emphasized the need for the collection of fossils being made by specialists themselves. The museum and laboratory workers should be encouraged to go into the field.

The PRESIDENT (Mr. R. D. OLDHAM) said that the papers had been of personal interest to him, as he had long been concerned with the *Glossopteris* flora and problems arising out of it, and had followed with interest the successive additions to our knowledge of the plant which for long was only known as impressions of

fronds. He could assure Mr. Edwards that in India the discovery of petrified remains of these plants, which would give some insight into the structure, had long been desired; but the search had, so far, been without success, in those beds which yielded *Glossopteris*.

Mr. Thomas thanked the Fellows for their reception of his paper, and expressed the opinion that it might prove possible to obtain cuticular preparations from some of the specimens of *Nummulospermum* figured by Dr. Walkom, although in the case of *Ottokaria* the plant-tissue had undergone a more complete change, and little trace of the outside surface was left. In reply to Dr. Davies, he said that the seeds which *Ottokaria* perhaps produced might possibly have been similar in form to those described as *Nummulospermum*; but the two structures differed considerably in size. He thought that knowledge of both forms was still so incomplete as to render any conclusions regarding their relation to *Glossopteris* very speculative. The main value of these communications was to draw attention to the various reproductive structures of doubtful affinities found with the *Glossopteris* flora, in the hope that further work and collections would show whether they belonged to *Glossopteris*, *Gangamopteris*, or to one of the other genera in this flora.

14. *The* Evolution *of Certain* Liassic Gastropods, *with special reference to their* Use *in* Stratigraphy.

By Agnes Irene McDonald, M.Sc., & Arthur Elijah Trueman, D.Sc., F.G.S. (Read May 4th, 1921.)

[Plate XXII.]

Contents.

[For the convenience of readers, it may be premised that matter of more general interest is mainly included in §§ I, III, and VII, and in the earlier portions of IV & V.]

I. Historical and Introductory Notes.

Gastropods are very suitable for evolutionary studies, for the shells are frequently well-preserved in fossils; while, owing to the mode of coiling, the development may be observed in any complete individual without breakage of the shell. Such studies on fossil Gastropods have shown that they illustrate clearly many of the biological principles that have been demonstrated by investigators of other groups, such as the Ammonites.

But, although Gastropods afford excellent material for palæontological researches of this nature, it is well known that apart from systematic work by numerous palæontologists, they have been comparatively neglected in this country. Further study is particularly desirable, since they are frequently abundant in formations where the fossils that are generally used in zoning are not common, and it is probable that a clearer understanding of the Gastropods will make it easier to correlate such rocks.

On the Continent a great deal more attention has been paid to the classification of fossil Gastropods, by E. Koken[1] and P. Fischer,[2] and more recently by Dr. A. E. M. Cossmann; the last-named author has produced several valuable monographs on the various groups, and his comprehensive 'Essais de Paléoconchologie Comparée' mark a great advance in the study of those fossils.[3] In the course of his work that author has found it necessary to subdivide

[1] 'Ueber die Entwickelung der Gastropoden vom Cambrium bis zur Trias' Neues Jahrb. Beilage-Band vi (1888–89) pp. 305–484 & pls. x–xiv.

[2] 'Manuel de Conchyliologie, &c.' Paris, 1880–87.

[3] See Bibliography, **2** & **3**.

many of the genera that had been proposed by earlier workers, and has shown that many of the older names cannot be applied so broadly as has been customary.

Very complete evolutionary studies of smaller groups have been published by Prof. A. W. Grabau[1]; while Miss Elvira Wood's work on the *Cerithium* group[2] is of similar nature, and will be referred to again later.

In the present paper it is proposed to consider the evolution of those slender Liassic gastropods which were formerly referred to the following genera:

Turritella, which included shells smooth, or with spiral ornament predominant; aperture holostome.
Chemnitzia, with axial costæ, spiral ornament feeble or absent; aperture holostome.
Cerithium, with both spiral and axial ornament present, these combining in many cases to produce granules and tubercles; aperture generally with a canal.

While these divisions may be recognized in a general way among recent Gastropods, the separation of Liassic species into three such groups is attended with considerable difficulty; most palæontologists in the past have attempted to classify them in this way, and the result in many cases has been confusing and unsatisfactory. This is chiefly due to the fact that the separation has been based largely on the form of the aperture, and such distinctions are difficult to apply, because—

(1) Apertural margins are rarely shown in fossil specimens.

(2) The Liassic species are so primitive that the characters in the aperture, which distinguish later forms, have not yet been evolved.

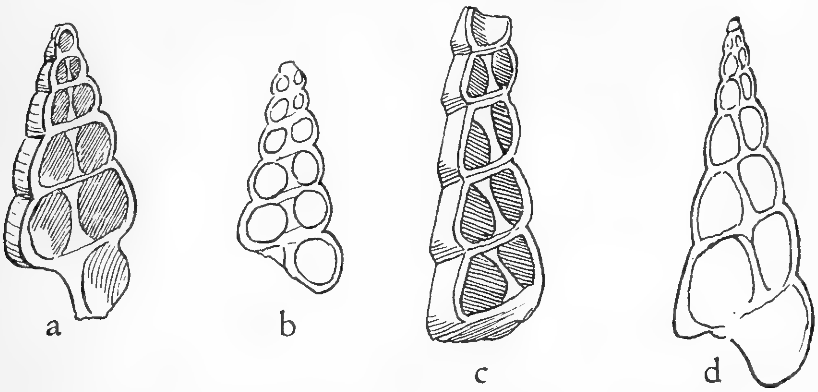
The Liassic species which were referred to *Chemnitzia* and *Turritella* are holostome, like the recent species of the corresponding groups. The Liassic species referred to *Cerithium*, however, are also generally holostome. Dr. Cossmann, among others, has pointed out that, although many of the Liassic species of the *Cerithium* group have no canal, some develop a feeble sinuosity on the lip, which in later Liassic and Inferior Oolite species has become a slight canal.[3] These species are separated with little difficulty from the other groups, when well-preserved specimens with oral margins complete are available; but it is clear that the difference in aperture, which may be regarded as a differential character in recent forms, is not so apparent in Liassic species.

Some workers, realizing the difficulty of classifying by the form of the aperture, have sought for other differential characters. Among these workers we may mention Terquem, who, paying attention chiefly to the form of the columella, found that it is

[1] **8**. The numerals printed in thick type refer to the Bibliography, § VIII, p. 340. [2] **29**.
[3] See, for example, **2**, vol. vii (1906) pp. 2–3.

almost straight in vertical sections of *Cerithium*, while in similar sections of *Turritella* it is markedly oblique.[1] This feature has not been much used in distinguishing the genera. Dr. Cossmann has suggested that it is unreliable[2]; but we have found the distinction to apply in every gastropod of which we have been able to make sections (see fig. 1).

Fig. 1.—*Sections of turriculate gastropods showing the characters of the columella. All enlarged about 3 times.*



a=*Procerithium ogerieni* (Dumortier), Lower Lias; *b*=*Cerithium* sp., recent; *c*=*Turritella* sp., recent; *d*=*Katosira* cf. *youngi* (Tate), Lower Lias. [In *a* & *b* the columella is straight; in *c* & *d* it is oblique.]

While it is possible to distinguish these several groups in a general way among Liassic species, these latter cannot strictly be referred to the genera *Cerithium*, *Chemnitzia*, and *Turritella*, for recent work has shown that these names must be restricted to more modern forms. New generic names, to cover special groups of Jurassic forms, have been proposed by Ralph Tate,[3] G. G. Gemmellaro,[4] and E. Piette,[5] and many additional names have been published by more recent workers; but these names have not been generally used in this country, and it will therefore be advisable to summarize briefly the classification as given by Dr. Cossmann,[6] omitting those details which are not required for the purposes of the present paper.

Cenacle **Cerithiacea** Cossmann.

Family PROCERITHIDÆ Cossmann.

This family was proposed to include most of the Mesozoic forms which were originally called *Cerithium*; they are generally ornamented, and have a simple aperture showing an early stage in canal development.

[1] **25**, pp. 236 *et seq.* The obliquity of the columella when part of the whorl is filed away is due to the slight helicoid spiral of the columella itself; thus in *Turritella* the helix is built up on a helicoid axis.
[2] **2**, vol. viii (1909) pp. 70–71.
[3] **19**. [4] **6**. [5] **25**. [6] **2** & **3**.

Procerithium Cossmann. Generally with granular ornament.
Cerithinella Gemmellaro. Flat whorls, ornamented with tubercles frequently forming a band along the margin of the whorls.
Cryptaulax Tate. Five pronounced axial ribs, continuous from whorl to whorl, forming a twisted pentagon.
Exelissa Piette. Spire pupoid, peristome detached.
Paracerithium Cossmann. Spire sub-spinous, whorls in steps.
Rhynchocerithium Cossmann. Granular ornament.

Cenacle **Loxonematacea** Cossmann.

Family Loxonematidæ Koken.

This family includes many of the species which were formerly referred to *Chemnitzia.* Aperture holostome, with a sinuous lip. Typically with axial ribs.

Zygopleura Koken. Sinuous axial ribs, no spiral ornament.
Katosira Koken. Similar to *Zygopleura*, but with spiral ornament present.
Anoptychia Koken. Costate early whorls, smooth later whorls.
Hypsipleura Koken. Flat whorls, straight ribs.
Rigauxia Cossmann. With thick oblique plications in many species; form variable.

Family Cœlostylinidæ Cossmann.

Shells more or less turriculate, with columella perforate.

Bourguetia Cossmann. With *Turritella*-form.

Family Pseudomelaniidæ Fischer.

Smooth forms resembling the Melaniidæ, but without a heterostrophic protoconch. Most of the Liassic species were formerly called *Chemnitzia.*

Family Mathildiidæ Cossmann.

Turritelliform shells with heterostrophic protoconch; holostome.

II. Terminology.

(A) Descriptive Terminology.

Various authors have used descriptive terms in different ways, and there is some confusion in comparing the species which they describe. This is particularly the case with terms relating to ornamentation; in Gastropods, as in Brachiopods and Lamellibranchs, costæ of two types may be developed, either parallel to or cutting the growth-lines, and it is necessary to state which type is present.[1] It is frequently difficult to determine whether the

[1] This difficulty was appreciated by the late Ivor Thomas and Dr. F. J. North in their work on Brachiopods, and they propose to restrict the term 'costæ' to ornament transverse to the growth-lines. See I. Thomas, 'The British Carboniferous *Producti*' Mem. Geol. Surv. (Pal.) 1914, pp. 225, 226; and F. J. North, 'On *Syringothyris*, &c.' Q. J. G. S. vol. lxxvi (1920) p. 164.

'ribs' mentioned by writers on Liassic Gastropods are transverse to or parallel to the growth-lines. For instance, Tate (even in the same paper) described both types of ornament under the term 'ribs.'[1]

It will be convenient, therefore, to distinguish clearly between these two styles of ornament; Mr. Buckman has put forward the two names transcrescent and concrescent, to cover ornament crossing growth-lines and ornament parallel to growth-lines respectively.[2] These are applicable to the Brachiopoda and all divisions of the Mollusca.

(α) Concrescent ornament.—This always follows the lines of growth, and may consist of striæ, folds, or costæ. In Gastropods it is also conveniently defined as axial ornament, since the ribs are in the direction of the axis of the shell.

(β) Transcrescent ornament.—This type of ornament cuts the lines of growth. In Gastropods it may also be defined as spiral ornament, since it follows the spiral of the shell. Primary and secondary (or intercalated) spirals are recognized; excessive development of one or more spirals leads to carination.

Either of these styles of ornament may occur independently; but they are usually associated, and give rise to other types, of which the following are the most characteristic :—

(*a*) In which the axials are strong, the spirals merely striæ : for example, *Procerithium slatteri*.

(*b*) In which spirals are strong, and axials are reduced to fine threads: for example, *Procerithium sinemuriense* (Martin).

(*c*) In which both axials and spirals are equally strong, and form a network: for example, *Procerithium equireticulatum*.

(*d*) In which both axials and spirals are equally strong, but tubercles arise at the points of intersection: for example, *Procerithium ogerieni* (Dumortier).

Protoconch.—The use of the term 'protoconch' in papers on Gastropods calls for some comment: the protoconch is not definitely marked off by a septum, as in Cephalopods, and so there is considerable difficulty in determining how far it extends. Some authors have applied the term to all the smooth whorls at the apex of the shell[3]; but these smooth whorls would appear to be comparable with the several embryonic whorls of Ammonites, and not with the protoconch simply. It thus appears to us that it is more suitable to use the name 'embryonic whorls' for the smooth whorls of Gastropods, and that the term 'protoconch' should be restricted to the earliest part only of the embryonic whorls.

[1] **20**, pp. 402, 405.

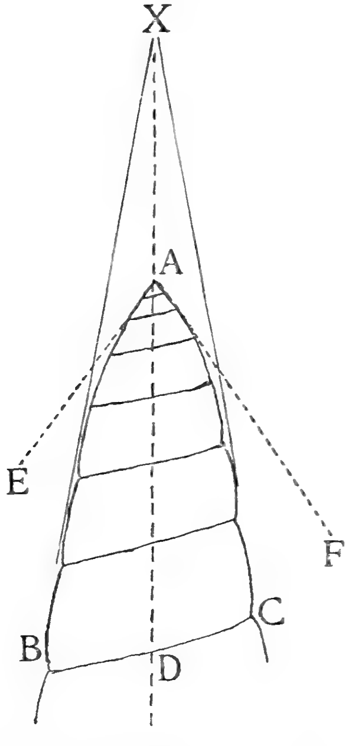
[2] See Ivor Thomas, *op. cit.* p. 226. In a letter to us (January 5th, 1921), Mr. S. S. Buckman suggests that transcrescent and concrescent are more appropriate terms than transcrescentic and concrescentic; he also proposes the term 'obliquicrescent' for ribs oblique to the growth-lines.

[3] **2**, vol. i (1895) p. 9; **8**, p. 9.

(B) Measurement of Gastropod Shells.

Apical angle is the angle made by the sides of the whorls at the apex.

Fig. 2.—*Diagram illustrating the terminology.*



[The angle ADB is the sutural angle; the angle EAF is the apical angle; and the angle BXC is the spiral angle.]

Spiral angle is used frequently with the same meaning, but very commonly the angle between the sides of the whorls changes during growth. It seems desirable, therefore, to use this latter term for the angle between the sides of the whorls at any stage. It can be measured, even if only two consecutive whorls are present.

Sutural angle, as used in this paper, is the angle made by the suture and the probable axis of the specimen (that is the angle ADB in fig. 2). This method of measurement is more useful in comparison than the more general way of taking the sutural angle to be the angle between the suture and the edge of the spire (that is, the angle ABD in fig. 2).

III. General Considerations.

As we have already noted, few evolutionary studies of fossil Gastropods have been published, the chief works of this kind being by Prof. A. W. Grabau and Miss Elvira Wood; these authors have shown that Gastropod evolution illustrates those biological principles which have been demonstrated among Ammonites by numerous workers. The Liassic gastropods that we have studied likewise exemplify many of these principles, and the study of these features is regarded by us as being of vital importance in constructing a natural classification of the Gastropods. In our opinion Dr. Cossmann's classification is open to criticism, because it takes little account of ontogenetic evidence, and thus may lead to the grouping-together of morphic equivalents on diverse lines of descent.[1]

Since the grouping of species that we propose in the present paper is based on a study of these evolutionary changes, it may prove useful to explain briefly several of the principles which are of importance in tracing the inter-relationships of these Liassic forms.

[1] See, for instance, E. Wood. **29**, pp. 2 & 3.

(1) Development of Ornament.

From an ontogenetic study it is possible to distinguish two clearly-marked groups of turriculate gastropods in Liassic rocks:

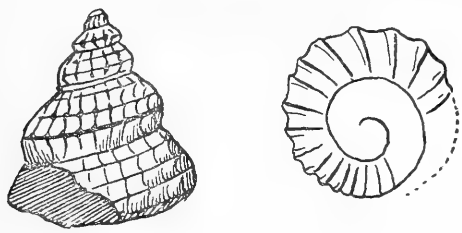
(i) A group in which spirals always appear before axials in development.

(ii) A group in which axials always appear before spirals.

The first group includes the Procerithidæ. In typical species of *Procerithium*, after one or more smooth whorls at the apex, a nearly median spiral appears; in the succeeding whorl a second (and posterior) spiral is developed, to be followed in many cases by the development of axial ribs, which form a network with the spirals.

On the other hand, in the development of *Zygopleura*, after a few smooth apical whorls, the earliest ornament to develop consists of axial ribs. In *Katosira* spiral threads are added to these in later development, and it may therefore happen in certain cases that the adult of *Katosira* resembles in some degree the adult of *Procerithium*; but, owing to the difference in the order of development of the axials and spirals, there is no difficulty in determining to which group such homœomorphic forms belong.

Fig. 3.—Turbo *sp. Lower Lias* (capricornus *zone*), *the Brickworks, Stonehouse (Gloucestershire).*



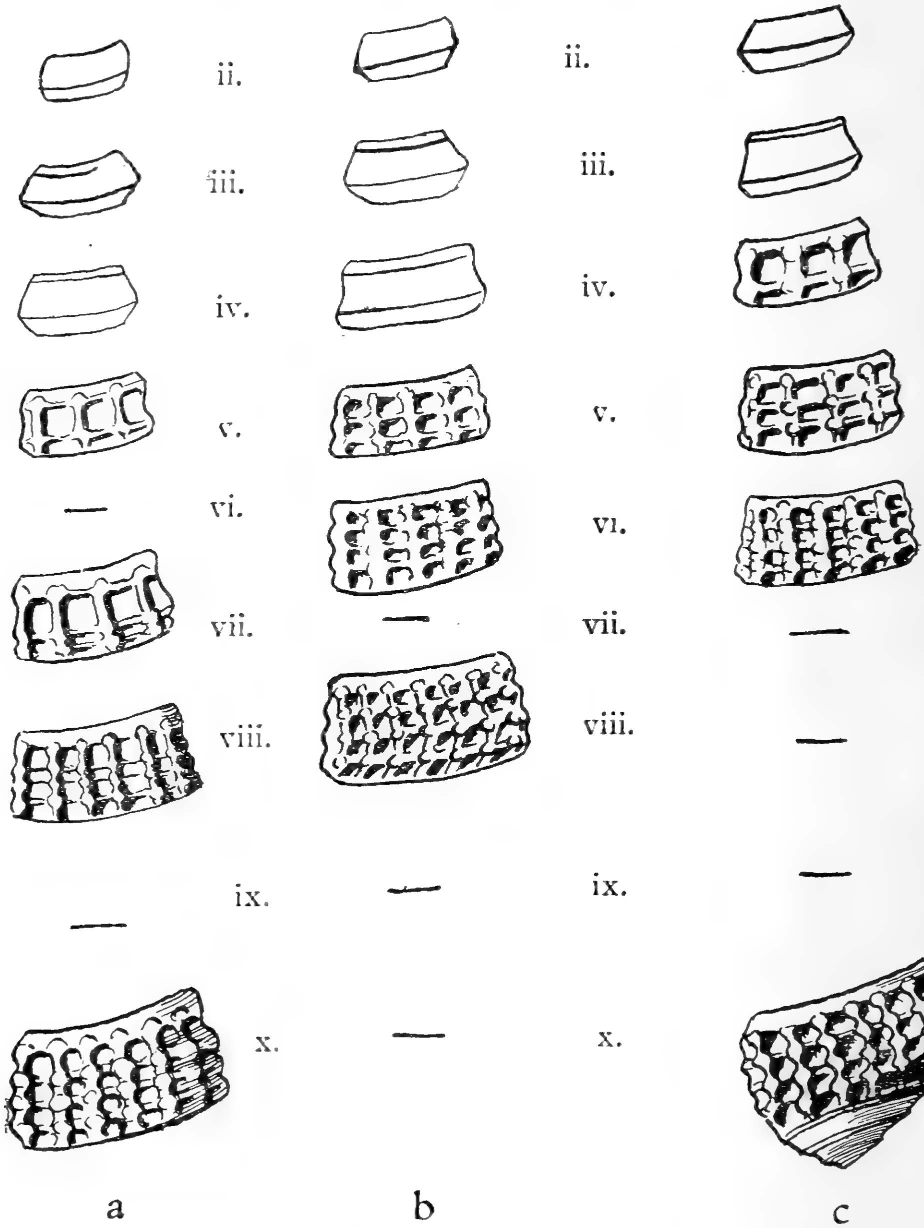
a b

a=Specimen × 3; *b*=Embryonic whorls from the same ×10.

This difference in the order of development of axials and spirals would naturally be of value in other families: for instance, in *Pleurotomaria similis* spirals appear before the axials, while in species of *Turbo* the axials appear before the spirals (fig. 3).

Changes in the shape of the whorl are largely associated with increase in number and prominence of the spirals, particularly in *Procerithium*. The smooth embryonic whorls are simple and rounded, becoming somewhat angular with the development of the first spiral. When a second spiral is added, the whorl becomes feebly bicarinate, and appears somewhat flat; and, even after a third spiral has been intercalated, there is no marked change in the shape of the whorl, the sutures appearing deep and wide, since they are bounded by prominent spirals. As further spirals are added, however, in more advanced species, the relative importance of the two primary spirals decreases, and the whorl becomes more rounded again. These changes in the shape of the whorl are to be seen in the development of many species of *Procerithium* (see fig. 5 *a*, p. 306).

Fig. 4.—*Diagram illustrating the acceleration of development in three related gastropods of the* Procerithium *cf.* slatteri *group.*



a=*Procerithium* sp., Lower Lias (*birchi* zone), Shekill's Brickyard, Pebworth (Gloucestershire). L. Richardson coll. L.G. 59.

b=*Procerithium* sp., Lower Lias, tunnel-heaps, Old Dalby (Leicestershire). L. Richardson coll. L.G. 13.

c=*Procerithium* cf. *slatteri* (Tate), Lower Lias (*jamesoni* zone), railway-cutting, Toddington (Gloucestershire). L. Richardson coll. L.G. 19.

[The Roman numerals denote the number of the whorl from the apex.]

(2) Acceleration.

In almost every series of related gastropods that we have studied the later members are more highly accelerated than the earlier. This is illustrated in a series of forms, probably genetically connected, which includes *Procerithium slatteri.* Three members of such a series are shown in fig. 4 (p. 304). It will be noticed that:

(1) The two-spiralled stage is retained later in the less-accelerated forms (fig. 4 *a*, iv).

(2) The axials appear earlier in *Procerithium* cf. *slatteri* than in the less-accelerated species (compare fig. 4 *c* iv with 4 *a* v).

(3) The network with four spirals is attained earlier in *Procerithium* cf. *slatteri* (fig. 4 *c* vi).

Numerous series of Liassic Loxonematidæ show a comparable acceleration, the earlier members having several smooth whorls near the apex, while the more highly accelerated forms have only one or two. Owing to slightly different rates of acceleration, it it is not uncommon to find that specimens collected at the same horizon show some variation.

(3) Catagenetic Gastropods.

In a few catagenetic species the ornament is retarded, when compared with the development of ornamentation of those species from which they are presumably derived. One of the best instances of this is *Procerithium numismale*, the development of which is compared with that of *P. ogerieni* in fig. 5 (p. 306). It will be noticed that:

(1) *P. numismale* retains the two-spiralled stage longer than *P. ogerieni.*

(2) Axials are not developed in *P. numismale* until half a whorl later than in *P. ogerieni.*

(3) The reticulate pattern is never so pronounced in *P. numismale* as in *P. ogerieni.*

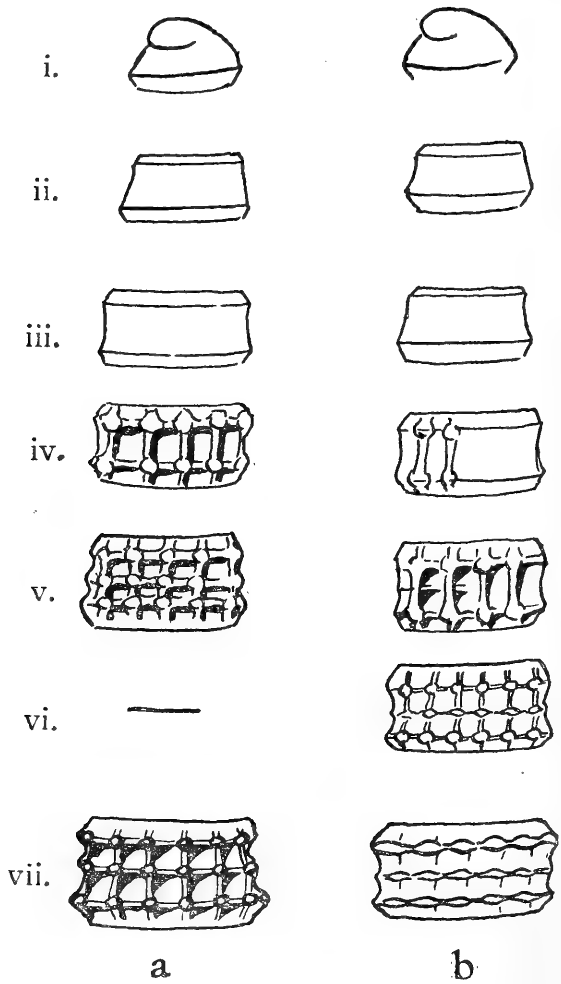
In the later stages it will be noticed that the axial ornament becomes feeble, the middle spiral losing its tubercles before the two outer spirals, and the last whorl suggesting a return to the two-spiralled stage. In quite a number of the specimens in which the ornament shows these retrogressive characters there is also a tendency to produce a pupoid form of shell, particularly among the Procerithidæ. These forms have generally been called *Exelissa*; but it is here suggested that they are catagenetic descendants of various species of *Procerithium* (see p. 317).

(4) Homœomorphy.

The chief difficulty in the natural classification of Liassic gastropods (indeed of most fossils) lies in the recognition of morphic equivalents or homœomorphs. Species occupying comparable

positions in parallel stocks are distinguished only with difficulty: for instance, carinate species of *Procerithium* of different stocks are extremely similar in general form and appearance.

Fig. 5.—*Diagram showing the retarded development in a species of* Procerithium ('Exelissa'), *compared with the development of* P. *cf.* ogerieni.



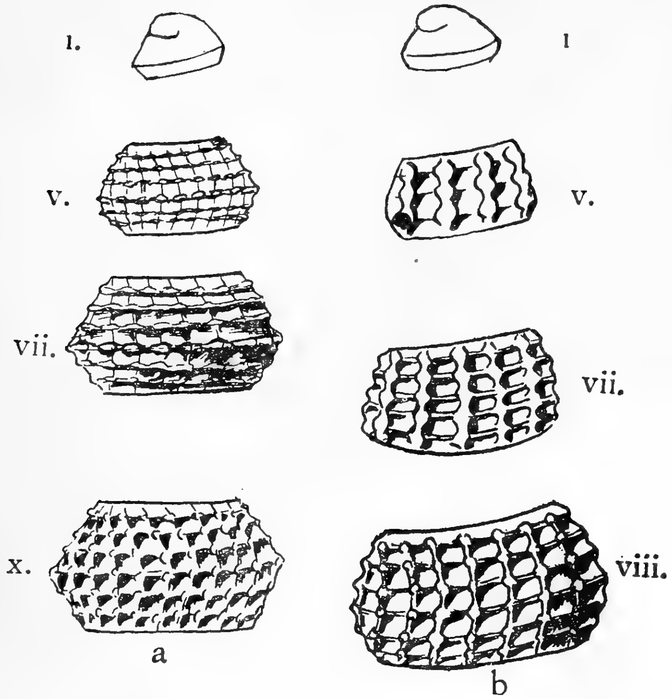
a = *Procerithium* cf. *ogerieni* (Dumortier), Lower Lias, tunnel-heaps, Old Dalby (Leicestershire). A. E. T. coll.
b = *Procerithium* ('*Exelissa*') cf. *numismale* (Tate), Lower Lias (*jamesoni* zone), Bishop's Cleeve Station, near Cheltenham. L. Richardson coll. L.G. 45.

Still more important is the separation of 'transversal homœomorphs.'[1] An example of this class is afforded by *Procerithium equireticulatum* and *P. liassicum*; *P. equireticulatum*, when

[1] S. S. Buckman, 'The "Kelloway Rock" of Scarborough' Q. J. G. S. vol. lxix (1913) p. 166.

young, has its spirals stronger than its axials, and the ornamentation is not normally reticulate until rather late in ontogeny. In *P. liassicum*, on the other hand, the early ornament consists of strong axials and feebler spirals, and in development the axials become relatively weaker, giving rise to a reticulate ornament similar to that of *P. equireticulatum*.

Fig. 6.—*Diagram illustrating the development of two homœomorphic gastropods of different descent (transversal homœomorphs).*



a = *Procerithium equireticulatum*, sp. nov., Lower Lias (*armatus* zone), railway-cutting, Toddington (Gloucestershire). L. Richardson coll. L.G. 7.

b = *Procerithium liassicum* (Tate), Middle Lias, Eston (Yorkshire). Tate Coll., Museum of Practical Geology, No. 7968.

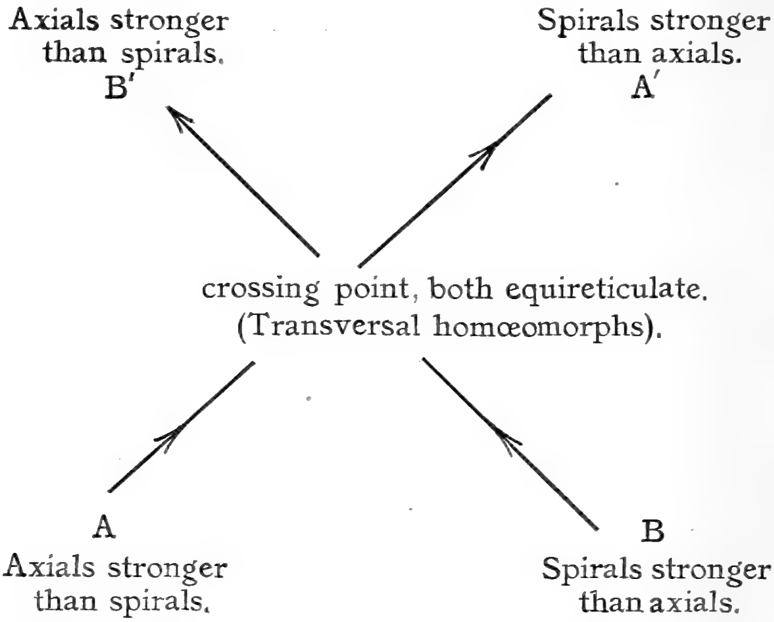
In each of these series, therefore, a stage will be reached in which the ornamentation will consist of spiral and axial elements of equal strength forming a fairly regular network. The later species of each series may pass beyond this stage; but their separation would not be difficult if the axials continue to change in strength. Yet at the 'crossing-point' of the two lineages, the members of the two series have at least a superficial similarity, especially if they possess similarly-shaped whorls; and their relationships are only made clear by a study of their ontogeny.

One other type of homœomorphy has also been indicated by Mr. S. S. Buckman in his work on Ammonites,[1] namely, cyclical

[1] *Op. jam cit.* p. 166.

homœomorphy. Examples of this are found among the gastropods of the *Zygopleura* group; primitively smooth forms may easily be confused with catagenetic smooth forms.

Fig. 7.—*Diagram illustrating transversal homœomorphy.*



[A A′=*P. liassicum* series. B B′=*P. equireticulatum* series.]

(5) Size of Gastropods.

Almost all the Liassic gastropods that we have studied are of small size, commonly less than 10 millimetres in length. Within many series there is a steady increase in size during anagenesis. The more primitive (radical) species are as a rule small; such are *Procerithium ogerieni* and *Zygopleura transversa*. If we adopt the terminology recently proposed by Mr. Buckman,[1] these may be called anamorphs. Certain Procerithidæ, presumably catagenetic, generally named *Exelissa*, are likewise usually small and are probably catamorphs. On the other hand, some later members of the *Zygopleura* series, described here as *Z. deleta*, in which the ornament is catagenetic, are bigger than the normal members of that group, and may be considered as megalomorphs.

(6) Classification.

The existing classification, as we have already noted, depends largely on the form of the oral margin, but these characters alone are insufficient to differentiate closely related stocks, since the development of a canal is itself a progressive character in the

[1] 'Type Ammonites' vol. iii (1919) p. 6.

Procerithidæ: the obliquity or straightness of the columella may also serve broadly as a differential character, but it is of little use for anything except the widest divisions. The soundest classification, therefore, takes into account the following characters:—

A. Differential.

(1) The nature of the ornament that first appears, whether axial or spiral.
(2) The character of the aperture, whether holostome or siphonostome (to be used with the reservation that most primitive forms are holostome).
(3) The obliquity or straightness of the columella.
(4) The character of the embryonic whorls, whether heterostrophic or homœostrophic.
(5) The curve of the growth-lines.
(6) The spacing of certain features of the ornament on the whorl.
(7) Differential acceleration or retardation of characters.

B. Progressive.

(1) Shape of whorl.
(2) The curve of the growth-line (or concrescent ornament).
(3) The form of the aperture (in canaliculate species).
(4) The size of the shell.
(5) The strength and character of the ornamentation.
(6) The contraction of the spiral angle towards the base.

In the detailed treatment of genera and species these characters are dealt with, and an attempt is made to show the relationships of the species. This has been possible in certain cases, since several series of specimens, presumed to represent actual lines of descent, have been available; but in no case have the later members of such lineages shown a very marked advance on the earlier members, and it has not been easy to trace the groups from zone to zone.

For these reasons it has not been possible to use in a satisfactory way many of the subgeneric names proposed by Dr. Cossmann, neither has it been deemed advisable to add any generic names at the present time. When further material is available for study, and relationships can be clearly established, more detailed classification may be possible; but, for the present, we propose to use the existing generic names, it being understood that in certain cases they cover several lines of descent.

IV. Family of the Procerithidæ Cossmann.

The fossils referred to this family are generally characterized by fairly simple mouth-form, with both spiral and axial ornamentation. In most species the axial and spiral types of ornament are approximately equal in strength, and give rise either to a lattice-type of ornament, or to feeble tuberculations. In a few species the axials are much more prominent; while in others, chiefly owing to the feebleness of the axials, the spirals appear most prominent.

So far as we have been able to determine, the columella in all these forms is straight.

In development, the various species are all alike in having smooth embryonic whorls, the first ornament to appear being a single median spiral, to which are subsequently added other primary and secondary spirals. Axial ornament never develops until after the appearance of one or more spirals.

Most of the species that we have examined are here referred to the genus *Procerithium*; Dr. Cossmann subdivides this genus into numerous sections, of which *Cosmocerithium*, *Rhabdocolphus*, and *Xystrella* may be mentioned.

Of the other genera named by Cossmann under this family we have examples of *Paracerithium*, which have been studied; this genus comprises subspinous forms in which the spirals are often faint, and the axials produced to a low tubercle on the posterior margin of the whorl. Similarly *Cerithinella* shows a characteristic type of ornamentation, with rows of tubercles near the suture. Probably these genera are correctly defined, because the style of ornamentation is sufficiently marked to serve as a real indication of relationship; the genus *Cryptaulax* may, perhaps, be admitted for the same reason.

On the other hand, the genus *Exelissa*, proposed by E. Piette to include forms in which, owing to the contraction of the later whorls, the shell becomes pupoid, probably is not a natural group; this question is fully considered later (p. 317).

The genera of the Liassic Procerithidæ dealt with in this paper are, therefore, as follows:—

Procerithium. Spirals and axials forming a network (often with tubercles). The spirals are, for the greater part, equally spaced. The oral margin shows a simple sinuosity.

Cerithinella. Whorls generally flat, ornamented by tubercles arranged in definite bands, often separated by a smooth space.

Paracerithium. Spire strongly ornamented with axials and sharp tubercles; the oral margin shows a stronger projection than *Procerithium.*

(A) Procerithium Cossmann.

This includes many Liassic *Cerithium*-like gastropods. Several groups may be recognized among the English forms that we have been able to study; but, beyond suggesting these, we do not propose to introduce any rigid scheme of generic classification based on present knowledge. It is certain that, despite the great number of species already described, there are still many more as yet unfigured; and, until more of these are known, it would merely cause confusion in the future to indicate new genera.

The chief group in the lower part of the Lower Lias consists of small forms, such as *Procerithium ogerieni*, *P. abcisum*, etc., which have rather flat whorls, separated by deep wide sutures, and ornamented by three spirals crossed by axials, accompanied by the formation of a network with low tubercles at the intersection.

From these forms, which may perhaps be regarded as constituting a central stock in Sinemurian times, many other forms evolved.

(i) Some by the addition of secondary spirals, and increase in the number of axials: for example, *P. liassicum*.
(ii) Some species become carinate by the accentuation of one spiral.
(iii) By the loss of axial ornament in catagenesis certain forms become ornamented with spirals only.
(iv) By gradual loss of ornament and contraction of spiral angle, forms become pupoid or of *Exelissa* type.

These changes must not be considered by themselves as indicating the natural grouping of the various species, but simply as showing the main trend of evolution; there is no doubt that each of these changes has taken place in several different stocks, some of these contemporaneously, others at different times.

Comparison of *Procerithium* with modern Cerithiidæ.

In the paper already cited,[1] Miss Elvira Wood has described in some detail the development of several recent and Tertiary Cerithiidæ. Among these are some differences due to relative acceleration; but in many forms the embryonic whorls and protoconch are about one and a half whorls in length, after which one or two spirals appear; if only one spiral is developed first, a second is added at a very early stage above the first. Axial ribs are developed at a somewhat later stage, often as early as the third whorl, and before the appearance of the third spiral; secondary spirals are intercalated at later stages.

It is interesting to compare the development of early Liassic species with these recent Cerithiidæ. In each case the order of development of the various features is similar; but the Tertiary and recent species are, on the whole, more accelerated than Liassic forms. For instance, the axial ornamentation in Tertiary forms usually appears during the third whorl, while in Liassic forms it rarely appears before the fifth whorl; the addition of secondary spirals in recent forms proceeds more rapidly than in Liassic species, and while the adult whorls of early Liassic species have typically three spirals and rarely more than four spirals (and Inferior Oolite species have typically four[2]), the recent species often have ten or more spirals.

Notwithstanding these differences due to the relative acceleration of the later forms, there is still a remarkable similarity in the development of these two groups, which suggests close relationship.

Procerithium ogerieni (Dumortier). (Pl. XXII, fig. 8 & text-fig. 5 *a*, p. 306.)

Cerithium ogerieni Dumortier (**5**, pt. 2, 1867, pl. xlv, fig. 6).
Procerithium ogerieni (Dumortier) Cossmann (**3**, text-fig. 15, p. 45).
Cf. *Cerithium decoratum* Moore (**11**, pl. xvi, fig. 14).

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[1] **29.** [2] **9**, pp. 145, 146.

Dimensions of our specimens.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
6·5 mm.	32 per cent.	69 per cent.	23°	107°

Our specimens appear to be identical with Dumortier's species; they are slender turriculate shells, having flat whorls ornamented with three rows of tubercles, and separated by fairly deep sutures. The oral margin is very rarely seen, but is always simple, and if any sinuosity is present it is very minute.

Development (see fig. 5 *a*).—The apex shows a smooth embryonic whorl, little more than one volution in length; a single spiral then appears in the anterior region, and by the succeeding whorl a second primary spiral is added above the first; this type of ornamentation lasts for two volutions, and then axials are developed, in such wise that two rows of tubercles joined by axial and spiral lines are produced. In the following whorl a single secondary spiral is intercalated between the two primaries, with the formation of three rows of tubercles, the pattern characteristic of the remainder of the shell. Owing to the prominence of the two primary spirals the whorl appears flat, and the borders of the sutures pronounced.

Locality and horizon.—The specimens were collected from the Lower Liassic clays of the tunnel-heaps, Old Dalby, Leicestershire (probably near the *oxynotus* zone). Similar specimens have been found by Mr. L. Richardson in the *turneri* zone, near Hester's Way Farm, in the neighbourhood of Cheltenham. Dumortier's specimen is also recorded from the *oxynotus* zone. Typical specimens have been presented to the British Museum of Natural History (G 24873–74).

PROCERITHIUM cf. QUINQUEGRANOSUM Cossmann.

Procerithium quinquegranosum Cossmann (**3**, pl. iii, figs. 1–3).

Dimensions of our specimens.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
6·6 mm.	34 per cent.	70 per cent.	25°	103°

Small specimens, with flat whorls separated by deep sutures; the ornamentation of the adult whorls consists of five rows of nodules. Oral margin simple.

Development.—The apical whorls are, unfortunately, not preserved in our specimens, but the two earliest whorls present are ornamented by two spirals; these are followed by one whorl with two rows of nodules, formed by the two spirals crossed by straight axials. The succeeding whorl has three rows, and is followed by two whorls with four rows of nodules; by this time, however, the axials have become curved, and the remaining whorls have the characteristic five rows of granules, which give the name to the species. It is interesting to note that the two primary spirals

are the most prominent throughout, with the consequence that the whorl remains fairly flat.

Procerithium quinquegranosum is sufficiently similar to *P. ogerieni* to be regarded as a member of the same stock; it is an advance on the latter, as shown by the increased number of spirals and the greater curve of the axial ribs.

A number of other specimens were examined from among material collected by one of us at Old Dalby,[1] and a form which may be regarded as intermediate between *P. ogerieni* and *quinquegranosum* was discovered.

Observations made have been summarized in the following table, in which *P. ogerieni* and *P. quinquegranosum* have been inserted for comparison.

	Number of smooth whorls.	Number of spirals of last whorl.	First axials to appear.	Number of axials to a whorl.	Character of axial ornament.
A. *P. ogerieni*	$1\frac{1}{2}$	3	5th or 6th whorl.	13	Straight.
B. Intermediate form ...	$1\frac{1}{2}$	4	5th whorl.	14	Curved.
C. *P. quinquegranosum*.	1	5	4th whorl.	16–18	Sharply curved.

It will be noticed that specimen A in the above table has very simple ornament, the first four whorls are smooth or ornamented by spirals only, and the last whorl has only three rows of fairly widely-spaced nodules; while specimen C has simple ornament for about three whorls only (axials appear by the fourth whorl), and by the last whorl the ornament is accelerated to such an extent that there are at least five rows of nodules present. It will also be noticed that, whereas in A the axial ornament is straight, with fewer ribs to the whorl, in C it is much more sharply curved, and the ribs are finer and more closely packed.

PROCERITHIUM cf. SLATTERI (Tate). (Text-fig. 4 *c*, p. 304.)

Procerithium cf. *slatteri* Tate (**20**, p. 406, & pl. xxvi, fig. 7).

Dimensions of specimens figured here.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
5·5 mm.	36 per cent.	67 per cent.	22°	112°

Very small forms, with rounded or subquadrate whorls, orna-

[1] Now in the Geological Department, University College, Nottingham. Typical specimens have been presented to the British Museum of Natural History (G 24875–81).

mented by four spirals crossed by strong axials bearing low nodulations at each intersection. The oral margin in the majority of the specimens examined is slightly angular anteriorly.

Development (see fig. 4 *c*).—The apex is preserved, and is smooth for about one volution; the next whorl is ornamented by a single primary spiral occupying a more or less anterior position, and on the next whorl a second primary spiral is added above the first. Strong axial ornament appears on the succeeding whorl, and persists throughout; an extra spiral is intercalated in the whorl following, and later (on the sixth whorl) a fourth spiral is added. The ornamentation found on the sixth whorl is continued unchanged (except for a greater curve of the axials) until the last whorl, which in our specimens is somewhat pupoid.

This species has probably arisen from species of the *Procerithium ogerieni* type by acceleration of the ornament, including the addition of a fourth spiral, and the loss of the flattened form of whorl associated with the increase in strength of the middle spirals.

Locality and horizon.—Our specimens are from the Lower Lias (*jamesoni* zone) in a railway-cutting at Toddington, near Winchcombe, Gloucester (Mr. L. Richardson's collection, L.G. 19). Tate's holotype is also recorded from the *jamesoni* zone, Cheltenham (**20**, p. 406).

Procerithium dayi (Tate).

Cerithium dayi Tate (**22**, p. 7).

Lectotype (chosen from Tate's specimens): Museum of Practical Geology, Jermyn Street, London, No. 7936.

Apparently this species is closely related to the foregoing; it differs, however, in the slightly stouter form of shell; in the more convex whorls; in the less pronounced axials; and in the number and arrangement of the spirals, which are not equally spaced, the three central (secondary) threads being closer together, and separated by a wider interval from the two primaries. The aperture has a slight sinuosity anteriorly.

Locality and horizon.—Tate's specimens are from the 'Middle Lias' of Down Cliff.

Procerithium raricostati (Tate).

Cerithium raricostati Tate (**22**, p. 8).

Dimensions of holotype.

Length (estimated).	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
5·3 mm.	41 per cent	68 per cent.	25°	113°

Holotype: A specimen in the Tate Collection, Museum of Practical Geology, Jermyn Street, London, No. 7962.

This species has slightly convex whorls ornamented by stout axial ribs and finer spirals; on the later whorls these are about eight in number. The network formed is oblong, owing to the

close spacing of the spirals, and the low tubercles appear to be elongated in the direction of the spiral. The holotype is slightly worn where exposed, and the true characters of the ornamentation are only seen at the sides.

The development cannot be made out in this specimen. *P. rari-costati* is probably related to the *P. slatteri* group, from which it differs in the number of spirals.

Locality and horizon.—The holotype, the only example of this species that we have seen, is from the Lower Lias (*rari-costatus* zone) of Churchdown.

PROCERITHIUM EQUIRETICULATUM, sp. nov. (Text-fig. 6 *a*, p. 307.)

Cf. *Cerithium camertonense* Moore (**12**, pl. iv, fig. 9).

Dimensions of holotype.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
12 mm.	41 per cent.	75 per cent.	24°	110°

Holotype: A specimen in Mr. L. Richardson's collection (L.G. 7).

A slender shell, whorls convex, with a median carina, ornamented by fine axial ribs, crossing spirals which are somewhat stronger than the axials, producing a network with scarcely perceptible granulations at the intersections. On the last whorl the equi-distant spirals are six in number, the third (counting from the anterior suture) forming a fairly well-marked carina. Mouth simple, or exhibiting a slight sinuosity in the anterior region.

Development.—The specimens are well preserved, and consequently the early development can be made out. The apex is smooth for about one volution, then a spiral makes its appearance in the anterior region; on the following whorl axial ornament is established, and extra spirals are added; by the fourth whorl the spirals number six, and the median carina is already present. It is thus a very accelerated type. It is important to note that in the early stages the spiral ornament is much stronger than the axial, but later becomes less markedly so.

Locality and horizon.—The holotype is from the Lower Lias (*armatus* zone) of the railway-cutting, Toddington, near Winchcombe, Gloucester. Similar specimens were found in the Lower Liassic clays at Old Dalby, Leicestershire (now in the collection of the Geological Department, University College, Nottingham).

PROCERITHIUM (EXELISSA) cf. NUMISMALE (Tate). (Text-figs. 5 *b* & 8, pp. 306, 316.)

Exelissa numismalis Tate (**19**, p. 417, and **20**, pl. xxvi, fig. 5).
Cf. *Exelissa grata* (Terquem) (Cossmann, **3**, pl. v, figs. 2–5).

Dimensions of our specimens.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
5·5 mm.	30 per cent.	80 per cent.	23°	110°

A slender form, whorls nearly flat, and separated by faint sutures; the whorls preceding the adult whorls are ornamented by three rows of nodules, and resemble somewhat those of *P. ogerieni*, but the posterior row of tubercles is more accentuated than the anterior set. Towards the base of the shell there is a gradual change in the ornamentation, the nodules become elongated in the direction of the spirals; there is also a change in the sutural angle, as a result of which the base is attenuated, and the shell becomes pupoid. Oral margin circular, no suggestion of a canal.

Development.—The apex shows a smooth embryonic whorl, one volution in length; a primary spiral then appears anteriorly,

Fig. 8.—Procerithium ('Exelissa') *cf.* numismale *(Tate)*. × *9. L. Richardson coll. L.G. 45.*

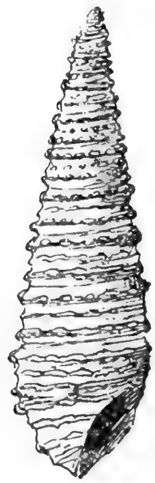
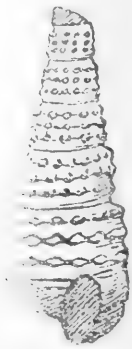


Fig. 9.—Procerithium ('Exelissa') ? numismale *(Tate)*. × *5. L. Richardson coll. L.G. 39.*



and by the succeeding whorl a second spiral is added above the first (and is not so pronounced as the first formed). This type of ornamentation is continued for two and a half volutions, after which axials are developed, producing two rows of nodules which by the following whorl have become equal in size, owing to the equalization in strength of the two spirals. A faint median spiral is then intercalated, producing the three rows of nodules characteristic of the remainder of the shell. As the adult whorls are approached, however, the axial ornament is gradually lost, the spirals (particularly the two anterior) becoming wavy lines. This latter peculiarity, along with the change in sutural angle, has been regarded by us as catagenetic. *Exelissa weldonis* Hudleston (**9**, pl. xi, fig. 8) may be regarded as a morphic equivalent of *Procerithium* (*Exelissa*) cf. *numismale*.

Locality and horizon.—The specimen described above is from the Lower Lias (*jamesoni* zone), Bishop's Cleeve Station,

near Cheltenham (Mr. L. Richardson's collection, L.G. 45). Similar specimens were found at the same horizon in a railway-cutting at Toddington, near Winchcombe, Gloucester (L. Richardson coll. L.G. 42 *a* & L.G. 39). These latter forms differ from *Procerithium* cf. *numismale* in having shallower sutures and a single spiral thread within the sutural depression. The three rows of nodules are approximately equal in size, the anterior row, however, may be stronger than the posterior set, the reverse of that which occurs in *P.* cf. *numismale.* Tate's specimen of *P. numismale* was found in the *jamesoni* zone of Cheltenham, and appears (from his description and the rather poor figure) to be almost identical with Mr. Richardson's specimens.

PROCERITHIUM (EXELISSA) cf. INFRALIASICUM (Cossmann).

Cf. *Exelissa infraliasica* Cossmann (3, pl. v, fig. 1, and pl. vii, fig. 20).

Dimensions of our specimen.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
4·4 mm.	40 per cent.	73 per cent.	26°	104°

A small pupoid form having slightly convex whorls ornamented with strong axials, which are faintly curved, crossing five unequally spaced, spiral threads. Oral margin simple.

Development.—The young of this form has three rows of nodules by the fifth whorl, increasing to four on the seventh whorl; all later whorls have five rows.

It differs from Dr. Cossmann's species in that it never develops seven spirals, and the whorls are not quite so convex. It may be considered a parallel development to *P. numismale*, but on a somewhat different line of descent, probably from a more advanced form resembling *P. slatteri.*

Locality and horizon.—Our specimen is from the Lower Lias (*jamesoni* zone) of Toddington, near Winchcombe, Gloucester (L. Richardson coll. L.G. 42 *b*).

Notes on the Generic Name *Exelissa.*

The name *Exelissa* was proposed by E. Piette to cover somewhat pupæform Cerithia in which the aperture is entire, the last whorl cylindrical and slightly contracted at the base. Numerous species have been referred to this genus by Piette and subsequent writers, an examination of figures of which shows that they include forms with many different variations in the character of the ornamentation; and it is here suggested that pupoid forms of Procerithidæ hitherto referred to *Exelissa* are merely catagenetic species of *Procerithium*, which have been developed independently at numerous horizons. This conclusion is deduced from the following facts:—

(1) There is great diversity in the ornamentation of species referred to *Exelissa.* On the whole, the pupoid species in the Lower Lias have

three spirals, and those of the Inferior Oolite have four spirals [1]: that is to say, in each case the ornamentation resembles that of the particular group of *Procerithium* from which we suggest that the pupoid form has been derived.

(2) The ornamentation of these pupoid Procerithidæ is frequently catagenetic on the last whorl; this was noticed in *P. numismale*, and is also shown by many figured species called *Exelissa* by Hudleston (**9**, pl. xi, figs. 5-9) and by Dr. Cossmann (**3**, pl. v).

(3) These species are invariably small, a fact which further accords with their catagenetic nature.

(4) The pupoid form is due to a contraction of the whorl near the base, the last whorl having become cylindrical, with an entire and somewhat detached peristome. It is extremely likely that these features are also catagenetic, the loss of the primitive canal being thus easily explained; while Prof. Grabau has noticed that similar characters are to be found in catagenetic gastropods at various horizons,[2] and probably in phylogerontic Fusidæ, where the inner lip often becomes detached from the columella and the whorl becomes somewhat cylindrical.[3]

On the other hand, it should be pointed out that there are certain species of *Procerithium* (and of *Zygopleura*) with catagenetic ornament which do not become pupoid, and there are also pupoid species in other families in which the ornamentation shows no trace of catagenesis; these facts do not appear to us to be seriously out of harmony with our suggestion, for among other groups, such as the Ammonites, catagenesis rarely affects all the characters at the same time.

If our suggestion, that these species do not constitute a natural group, should prove to be correct, the name *Exelissa* must not be applied so widely as has hitherto been the case, and in the naming of these forms two alternatives present themselves: either new generic names must be proposed for each catagenetic offshoot from *Procerithium*, or the whole of the species must be retained under the name *Procerithium*. This latter course has been adopted, since our knowledge of these forms is not sufficiently complete to allow of detailed classification, even if such detail is desirable at present.

PROCERITHIUM LIASSICUM (Tate) *non* Moore. (Text-fig. 6*b*, p. 307.)

Cerithium liassicum Tate (**24**, pl. ix, fig. 18).
Cf. *C. liassicum* (Moore) (**12**, p. 201 & pl. iv, figs. 16–17).
Cf. *C. ilminsterense* (Moore) (**12**, p. 200 & pl. iv, fig. 12).

Dimensions of holotype (estimated).

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
7·5 mm.	45 per cent.	66 per cent.	30°	108°

Holotype: A specimen in the Tate Collection, Museum of Practical Geology, Jermyn Street, London, No. 7968.

This form apparently differs from Moore's specimen in being

[1] **9**, pl. xi, figs. 5–7.
[2] A. W. Grabau, 'Principles of Stratigraphy' 1913, p. 973.
[3] *Id.*, **8**, pp. 5, 96.

stouter. It is ornamented by equally-spaced spirals and axials, which produce sharp denticulations where they cross. The form of the aperture cannot be determined.

Development (see fig. 6 *a*, p. 307).—The upper whorls are not clear in Tate's type-specimen, but in a smaller specimen in the same collection, the only ornament present to the end of the fourth whorl consists of one or more spirals; and not until the fifth whorl are these crossed by axials. The axials rapidly become strong, and by the sixth whorl the shell has three spirals crossed by axials, producing a coarse network, with sharp tubercles at the points of intersection. Throughout the remainder of the shell this ornamentation is retained, but becomes relatively finer as additional spirals are intercalated. On the penultimate whorl, six spirals are present; and, since the spirals are closer than the axials, an oblong reticulation is produced. The aperture is not clearly visible, but there are some signs of an anterior sinuosity.

Locality and horizon.—The holotype is a specimen from the Middle Lias of Eston (Yorkshire).

PROCERITHIUM cf. VENDÆENSE Cossmann.

Small slender forms which appear to be referable to this species in having numerous flat whorls, with a small apical angle not exceeding 20°, and exhibiting the characteristic ornamentation of Dr. Cossmann's figured specimen. Aperture indistinct.

The material that we have examined includes several varieties: some are strongly costate on the last whorl preserved, others show the catagenesis characteristic of the species (that is, axials are confined to the upper whorls, and the later whorls are ornamented by spirals only).

These forms may be regarded as coming from a primitive three-spiralled stock; but, while the forms constituting this group have flat whorls separated by deep sutures, they have stronger and more widely-spaced axials than species of the *P. ogerieni* group. A point of great interest is that these specimens show catagenesis of ornament approximately of the type shown by *P. numismale*, but the shells exhibit no tendency to assume a pupoid form.

Locality and horizon.—The numerous specimens which we refer to this group were found by Mr. J. W. Tutcher in Moore's 'Gutter-Bed' (*angulata* zone), Whitchurch, near Bristol.[1]

PROCERITHIUM SUBFISTULOSUM (Tate). (Text-fig. 10, p. 320.)

Cerithium subfistulosum Tate (**22**, p. 8).

Dimensions of specimen presumed to be the holotype (estimated).

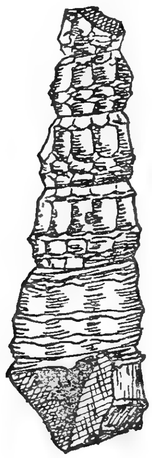
Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
40 mm. ?	18 per cent.	85 per cent.	15°	98°

[1] C. Moore, 'On Abnormal Conditions of Secondary Deposits, &c.' Q. J. G. S. vol. xxiii (1867) p. 497. See also W. Lonsdale, 'On the Oolitic District of Bath' Trans. Geol. Soc. ser. 2, vol. iii (1832) p. 244.

Holotype (?): A specimen in the Tate Collection, Museum of Practical Geology, Jermyn Street, London (No. 7964) is probably the holotype, but the locality does not agree with those mentioned by Tate (see below).

This form somewhat resembles those referred to *P.* cf. *vendæense*; but it differs in its greater size and in its convex subcarinate whorl. The apical whorls are not preserved in the holotype, so its development cannot be described. Each whorl present is ornamented by three prominent spirals, unequally spaced, the second forming a carina anteriorly. The suture is deep, and immediately above it on each whorl there is a fine spiral thread. The spirals are crossed by coarse widely-spaced folds, which rapidly become feebler and are scarcely visible on the last whorl. The oral margin is not clear, but it is probably oval.

Fig. 10.—Procerithium subfistulosum *(Tate)* ×2.



This species resembles to some extent *P.* cf. *vendæense* in its slender form, three main spirals, and gradual loss of axial ornament. Notwithstanding this fact, the differences in shape of the whorl suggest that the form now described belongs to a different line of descent. It may be related to *Procerithium trinodulosum* (Martin).[1]

Locality and horizon.—The specimen described is from the Lower Lias of Redmile (Lincolnshire), and is preserved in the Tate Collection, Museum of Practical Geology, No. 7964. Ralph Tate, in his original description, states that his specimen was from the Marlstone of Lincolnshire. This species is also recorded from the *semicostatus* zone of Redmile.[2]

Procerithium tenuiornatum, sp. nov. (Text-fig. 11, p. 321.)

Cf. *Chemnitzia foveolata* Tate (**24**, p. 353 & pl. ix, fig. 12).
Cf. *Turritella* sp. (**16**, pl. xv, fig. 1).

Dimensions of holotype.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
12·5 mm.	30 per cent.	72 per cent.	24°	105°

Holotype: A specimen in Mr. L. Richardson's collection, L.G. 63.

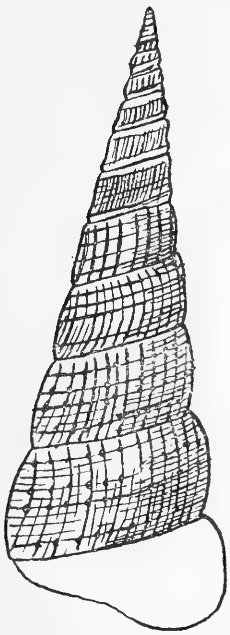
A slender gastropod, with rather flat or slightly convex whorls and very fine ornament, consisting of numerous spirals crossed by

[1] **10**, Pl. ii, figs. 15 & 16.
[2] C. Fox-Strangways, 'The Geology of the Country near Leicester' Mem. Geol. Surv. 1903, p. 106.

closely-placed axials. Oral margin not complete in the holotype, but in a topotype it shows a distinct sinuosity anteriorly.

Development.—This form has a smooth embryonic whorl, followed immediately by a stage with one spiral forming a carina; by the following whorl a second spiral has appeared, which in the course of the next two whorls becomes almost equal in strength to the first; from this point onwards to the eighth whorl, the whorls are flattish and feebly bicarinate, the spirals being near the sutures. Meanwhile, fine slightly curved axials have appeared in the space between the two primary spirals, and several finer secondary spirals have been intercalated. By the ninth whorl the two median spirals, which are fairly close together, have become at least equal in strength to the two primaries (and bear tiny tubercles where they are crossed by the axials), and give to the shell a slightly convex appearance. In the remaining whorls these four spirals are still prominent, while other finer spirals are intercalated. There is considerable variation in the spacing of the axials in the holotype: in the first few whorls the axials are strong, and on the eighth whorl are only twenty in number; there is a rapid change, however, on the following whorl, the coarse axials giving place to some fifty fine striæ; on the succeeding whorl again there is a return to coarse ornament, while a portion of the eleventh whorl has fine striations, and on the last whorl fine and strong axials are to some extent alternate. The aperture is not seen in the holotype; but, if we judge from topotypes, it would be approximately subquadrate. The flatness of the whorl is probably due, as we have noted in several more primitive species, to the prominence of the two primary spirals.

Fig. 11.—Proceritheum tenui-ornatum, *sp. nov.* *Holotype* × *5.*



[Lower Lias (*armatus* zone), Folly Lane Brickworks, Cheltenham. L. Richardson coll. L.G. 62.]

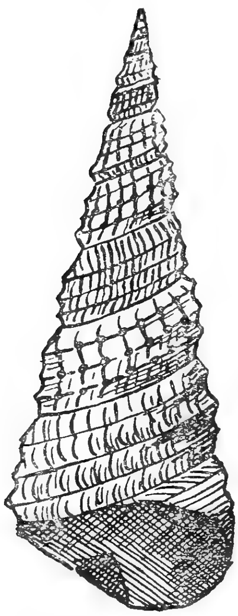
In Mr. L. Richardson's collection are numerous specimens approximating to this form, but with many variations in detail (for instance, the strength of the axials and the position of the accentuated spirals); all are alike, however, in their fine ornament, and in their flattish whorls showing some degree of bicarination in development.

This species is probably closely related to *Procerithium foveolatum* (Tate). That writer in his description drew attention to the

features that we emphasized in development, and to the flattish whorls. It would seem that *P. foveolatum* differs from *P. tenuiornatum* in possessing a greater number of spirals at all stages of development, and in the coarser axial ornament in the adult.

These two species obviously belong to another division of the Procerithidæ, separate from all those considered previously; the existence of the bicarinate young is reflected in the bicarinate stages in some species just considered, but in *P. tenuiornatum* and *P. foveolatum* it is retained to a later stage: that is, until some time after the axials have appeared.

Fig. 12.—Procerithium *cf.* tenuiornatum × *5.*



These forms evidently belong, therefore, to a somewhat more primitive group than those that we have been considering, which have a prominent three-spiralled stage. This latter type is, however, illustrated by a specimen (fig. 12) from the Lower Lias (*jamesoni* zone), from the railway-cutting at Toddington, near Winchcombe, Gloucester (L. Richardson coll. L.G. 51), which closely resembles *P. tenuiornatum* in form and ornamentation, but differs in that, by the sixth whorl, three rows of nodules are present; it probably represents a type more advanced than *P. tenuiornatum.*

Locality and horizon.—The holotype is a specimen from the Lower Lias (*armatus* zone) of Folly Lane, Cheltenham.

(B) Cerithinella Gemmellaro, *emend.* Cossmann.

Elongated shells, whorls almost flat, spiral angle low, aperture quadrangular; ornamentation: spiral lines crossed by twisted axials, producing tubercles arranged in groups or bands, often near the suture.

Cerithinella cf. confusa (Tate). (Text-fig. 13, p. 323.)

Cerithium confusum Tate (**23**, p. 205).
Cerithium (*Cerithinella ?*) *confusum* Wilson & Crick (**28**, p. 301 & pl. ix, figs. 2–2 *a*).
Cf. *Cerithinella ? terebellopsis* Cossmann (**3**, pl. vi, figs. 4–5).

Dimensions of our specimen (estimated).

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
20 mm.	20 per cent.	80 per cent.	12°	100°

A slender flat-whorled form, with a low apical angle and characteristic ornamentation.

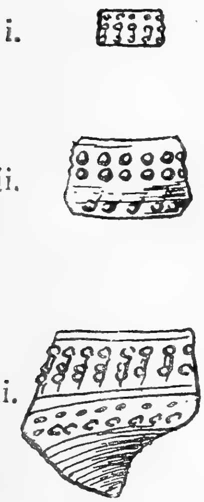
Development.—The earliest whorls are not present in our specimen; on the first whorl preserved are three rows of nodules, at first evenly-spaced and practically equal in size (fig. 13 i), but before the end of the whorl a space has appeared between the two anterior rows; for several succeeding whorls this style of ornamentation is retained, there being several unbroken spiral threads separating the two posterior from the anterior row of nodules. On the tenth whorl present in our specimen the ornamentation is similar; but the nodules appear to be isolated rather than raised portions of the axials (see fig. 13 ii). In the last whorl the nodules of the second row, counting from the posterior end, become elongated along the lines of growth and divide into two; the base of the shell is ornamented with spiral threads (fig. 13 iii).

Fig. 13.—Cerithinella *cf.* confusa *(Tate)*.

i.

ii.

iii.



[i=first whorl present in specimen; ii=eighth whorl present; iii=last whorl.]

Our specimen appears to resemble closely a specimen from the same locality figured by Wilson & Crick. It is not, however, so far advanced as the type of Tate's species, in which the posterior portion of the whorl is ornamented by five rows of nodules, separated from the two anterior rows by a band with spirals only. It is possible that *C. confusa* (Tate) merely represents a more fully grown specimen than the one that we have been considering; but in any case the two forms evidently are closely connected, the extra row of nodules having been developed as seen in the development of our specimen.

Other species of *Cerithinella* found in the Lias appear to be closely related to these, since most of them are alike in having the granules concentrated in two bands, separated by a zone with spirals only. We have been unable to obtain complete specimens of *Cerithinella* in which the development can be worked out; but, from the incomplete specimen of *C.* cf. *confusa*, it seems possible that this group of forms has been evolved from more normal forms of Procerithidæ.

Locality and horizon.—The specimen examined, in the collection of Mr. J. W. Tutcher (No. 1010), is from the Upper Lias, *acutum* zone, of Tilton (Leicestershire).

(C) Paracerithium Cossmann.

Shell fairly stout, aperture oval, terminated by a short projection; spire very heavily costulate, with spines near the posterior margin.

Paracerithium sp. (Pl. XXII, fig. 9.)

Dimensions of our specimens.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
17 mm.	40 per cent.	64 per cent.	20°	115°

Short spinous forms not sufficiently well preserved to show development, though it appears that the ornamentation on the early whorls consists of simple axials. The axial ribbing of later whorls is very pronounced, not more than ten or twelve to a whorl, with wide interspaces and projecting tubercles near the posterior suture, giving to the shell a stepped appearance.

As Cossmann's classification suggests, *Paracerithium* belongs to a different group of the Procerithidæ from *Procerithium*; probably it is more ancient (**3**, pp. 1–8). We have been unable to study any examples of *Paracerithium* earlier than this Toarcian form, and therefore we are unable to suggest with any certainty what may have been the line of evolution of the *Paracerithium* group. The species of *Paracerithium* figured from earlier zones in the Lias by Dr. Cossmann, however, indicate that the genus was probably evolving slowly: for instance, *P. ferrendum* Cossmann, from the Charmouthian, is not very different from the species that we have been describing.

It is not unlikely, however, that some of the spinous species referred to *Paracerithium* are merely sharply tuberculate species of *Procerithium*.

Locality and horizon.—Our specimens were found in the Oolite Bed, *falcifer* zone, of the Upper Lias, Grantham.[1]

V. Family of the Loxonematidæ Koken.

This family includes gastropods from Palæozoic as well as Mesozoic rocks. The Liassic species are generally simple in form and ornamented by axials, which may or may not be crossed by spirals; whenever spirals are present, they are almost always finer than the axials, wherefore 'tuberculation' is exceptional in this family. These forms in the past were generally referred to *Chemnitzia* and *Melania*; and, so far as we have been able to determine, all are alike in having axial ornament first in development, and a more or less oblique columella. In most forms the oral margin is comparatively simple, the aperture holostome, and the lip more or less sinuous. Dr. Cossmann, to some extent following Koken and other workers, has subdivided this family into some fifteen sections, not all of which, however, are found in Jurassic rocks.

[1] A. E. Trueman, 'The Lias of South Lincolnshire' Geol. Mag. 1918, p. 107.

Loxonema, known only in Palæozoic and Triassic rocks, and presumably ancestral to the other genera, is ornamented by sinuous striæ, sometimes with spirals and more rarely with axial ribs; the genus *Zygopleura*, which occurs in Liassic rocks, has curved axial ribs without spiral ornament: while the section *Katosira*, which we propose to treat as a genus, resembles *Zygopleura*, except that it has spirals; *Hypsipleura* has flat whorls and straight axial ribs. The genus *Anoptychia* proposed by Koken is taken by Cossmann to include species with flat whorls ornamented by ribs (in the early stages), which become obsolete on the last whorls; it appears to us that this genus may include homœomorphs of different stocks. The genus *Rigauxia*, as interpreted by Cossmann (**3**, pp. 206 *et seqq.*) has been made to include two distinct types:

(*a*) Species with a high sutural angle, deep narrow sutures, and a flat or even concave whorl, generally smooth or nearly so.
(*b*) Species with numerous spirals, widely-spaced oblique folds, and imbricate whorls with shallow concave sutures.

The species of the former group, of which the genotype *Rigauxia canaliculata* is a member, are mainly found in post-Liassic rocks, while those of the latter group appear in Liassic rocks. These species do not seem to us to be so clearly related to the *R. canaliculata* type as they are to certain species of *Katosira*, from which they appear to have been evolved, and we propose to group them with that genus.

We classify Liassic Loxonematidæ, briefly, as follows:—

Zygopleura: whorls convex, sinuous axials, no spirals.
Katosira: resembling *Zygopleura*, but spirals are present.
Hypsipleura: whorls flat, straight axial ribs.

It appears that *Zygopleura* has evolved from the smooth *Loxonema* in pre-Liassic times; *Katosira* may be regarded as a further development, probably from some form of *Zygopleura*; while *Hypsipleura* may represent a similar but parallel development.

This family exhibits the various stages of growth and decline that we have recognized in the Procerithidæ; but, while there are catagenetic forms with diminished ornament, there are no traces of contraction of the whorl towards the base, such as are observed in '*Exelissa*.' On the other hand, some species of both *Katosira* and *Zygopleura* show a tendency in later stages to mould the posterior portion of the later whorls on the preceding whorls: that is, the whorls become imbricate.

(A) Zygopleura Koken.

Probably represents an old genus evolved from *Loxonema* by the development of ribs. According to Dr. Cossmann, *Zygopleura* is not found higher than the Lias; it is extremely common in English Charmouthian rocks, but very few forms are obtained in higher formations. The earliest species of *Zygopleura* that we have studied; namely, those from the Rhætic and Hettangian, are

strongly costate with widely-separated ribs; later forms in each series become more finely ornamented, and the axial ribs become more curved with, in some cases, a return to the smooth condition; while other species, especially those in the Upper Lias, have imbricate whorls.

Zygopleura sp. (Text-fig. 14 *a*, p. 327.)

Dimensions (estimated) of our specimen.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
10 mm.	45 per cent.	75 per cent.	25°	105°

Fairly slender shell; whorls flat, separated by faint sutures, and ornamented with straight, coarse, widely-separated axial ribs.

Development.—Little can be said concerning the development of this individual, for the earliest whorls are not present, and all those preserved are similarly ornamented with simple ribs, as above described.

This species, if we judge from its simple ornamentation and low horizon, most probably represents the primitive stock that ultimately gave rise to the series of simply-ribbed *Zygopleura*.

Locality and horizon.—The specimen described is from the Rhætic at Blue Anchor, and is in the collection of Mr. J. W. Tutcher, No. 1009.

Zygopleura cf. transversa (Blake).

Cf. *Chemnitzia transversa* Blake (**1**; also **24**, pl. x, fig. 21).

Dimensions of our specimen.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
5·5 mm.	36 per cent.	72 per cent.	23°	110°

Small slender form, with flat whorls separated by rather feeble sutures; the ornamentation consists of widely-separated, slightly-curved, axial ribs.

Development.—Three apical whorls quite smooth, fourth whorl ornamented by about seven thick straight ribs; in the later whorls the axial ornament becomes very slightly curved.

The only point of difference between this form and the form previously described is the curvature of the axial ribs.

Locality and horizon.—The specimens were collected from the Lower Liassic clays on the tunnel-heaps of Old Dalby (Leicestershire), and are now in the collection of the Geological Department, University College, Nottingham.

Zygopleura cf. blainvillei (Münster). (Pl. XXII, fig. 1 & text-fig. 14 *c*, p. 327.)

Cf. *Melania blainvillei* Münster (**7**, pl. cxcviii, fig. 9).
Cf. *Cerithium henrici* Martin (**10**, pl. ii, figs. 17–18).
Cf. *Chemnitzia henrici* Moore (**11**, pl. xvi, fig. 12).
Cf. *Chemnitzia poleymiaca* Dumortier (**5**, pt. 1, 1864, pl. xviii, fig. 9).

Dimensions of our specimen (estimated).

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
9 mm.	30 per cent.	77 per cent.	22°	111°

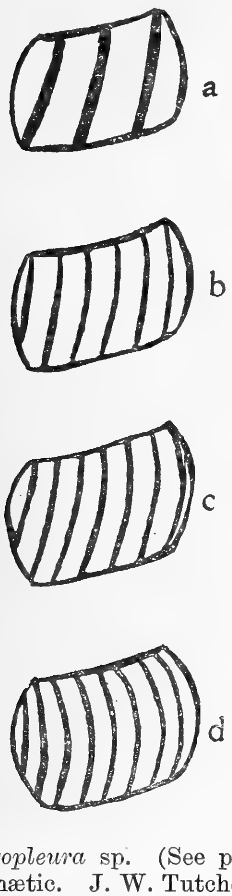
Fairly slender form, whorls almost flat, separated by well-marked sutures, ornamented by moderately-fine, slightly-curved, axial ribs. It should be noted that *Zygopleura blainvillei* does not include those forms with spiral ornament that have frequently been called *Chemnitzia blainvillei*, for they are species of *Katosira*.

Development.—Apical whorls not preserved; the first whorl present, probably the third, is smooth, and is followed by a whorl ornamented with simple, straight, axial ribs, not widely separated. This type of ornament persists through several volutions; but, as the adult whorls are approached, the ribs tend to become increasingly curved.

Locality and horizon.—Our specimen is from the Lower Lias (*armatus* zone) from the brickworks, Folly Lane, Cheltenham, and is in Mr. L. Richardson's collection (L.G. 8). Another specimen in the same collection (L.G. 30) from the *oxynotus* zone, near Rugby, resembles the preceding very closely; but the ribs are, if anything, somewhat coarser, and show no tendency to become curved, features which one might expect in a related form from a lower horizon. Forms closely resembling the above were also found in the Lower Liassic clays on the tunnel-heaps at Old Dalby (Leicestershire); the majority of these, however, are slightly more advanced, for the axial ribs are closer together and slightly more curved (text-fig. 14 *d*).

Typical examples of this species have been presented to the British Museum of Natural History (G. 24870–72).

Fig. 14.—*Diagram showing the adult whorls of various species of* Zygopleura.



a=*Zygopleura* sp. (See p. 326.) Rhætic. J. W. Tutcher coll. No. 1009.
b=*Zygopleura* sp. (related to *c*). L. Richardson coll. L.G. 30.
c=*Zygopleura* cf. *blainvillei*. Same collection, L.G. 8.
d=*Zygopleura* cf. *blainvillei*. J. W. T. coll. No. 1004.

ZYGOPLEURA DELETA, sp. nov. (Text-fig. 15.)

Cf. *Chemnitzia nuda* Tate (**24**, pl. x, fig. 9).

Dimensions of holotype (estimated).

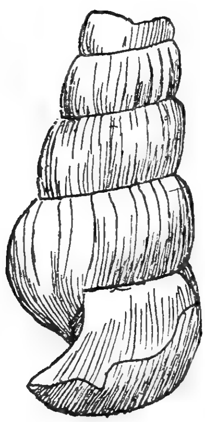
Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
30 mm.	29 per cent.	80 per cent.	25°	107°

Holotype: Specimen now in the Department of Geology, British Museum (Natural History), G. 24869.

A large form with feeble costæ giving place to very faint curved striæ. The whorls are convex, with a slight angularity near the posterior suture. The mouth is incomplete; oval. The holotype is slightly crushed.

Development.—The shell is incomplete, and all the apical whorls are missing; but the earliest whorl preserved appears to be smooth, while the next is subcostate. During the succeeding whorls, however, the costæ become fainter, and the last whorl is ornamented by faint curved growth-lines only.

Fig. 15.—Zygopleura deleta, *sp. nov. Holotype* × 2.



This form may be regarded as a catagenetic development from some form resembling *Z.* cf. *blainvillei.* Among the gastropods from the tunnel-heaps at Old Dalby are found several examples intermediate between *Z.* cf. *blainvillei* and *Z. deleta*, in which the ribs are confined to the middle and upper whorls, but become obsolete on the last whorl; the series from *Z.* cf. *blainvillei* to *Z. deleta* shows progressive increase in size.

The species just described differs from *Turritella nuda* Münster, chiefly in the absence of spirals, and from *Chemnitzia nuda* Tate, in the different curve of the striæ and the slightly angular whorl.

Locality and horizon.—The holotype is a specimen from the Lower Liassic clays, from the tunnel-heaps at Old Dalby (Leicestershire).

ZYGOPLEURA NUDA (Tate) *non* Münster. (Text-fig. 16, p. 329.)

Cf. *Chemnitzia nuda* Tate (**24**, pl. x, fig. 9).

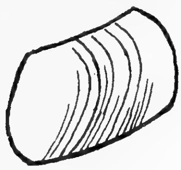
Dimensions of holotype (estimated).

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
27 mm.	30 per cent.	77 per cent.	20°	103°

Holotype: A specimen in the Tate Collection, Museum of Practical Geology, Jermyn Street, London, No. 7993.

A smooth slender form, with convex whorls showing no trace of angularity, smooth throughout, or ornamented by exceptionally fine growth-lines; with no trace of costæ at any stage in development, and no spirals. Mouth incomplete; oval.

Fig. 16.—Zygopleura nuda *(Tate)* non *Münster. Diagram showing the curve of the growth-line.*



This specimen differs from *Zygopleura deleta* in the rounded whorl and in the greater curve of the growth-lines, and it appears to differ from *Turritella nuda* Münster, to which it was referred by Tate, in the absence of spirals.

Locality and horizon.—The holotype is from the Middle Lias of Huntcliff (Yorkshire).

ZYGOPLEURA CAPRICORNU, sp. nov. (Text-fig. 17.)

Dimensions of holotype.

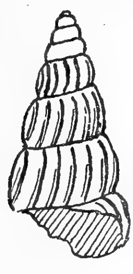
Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
3 mm.	42 per cent.	67 per cent.	30°	105°

Holotype: A specimen in Mr. L. Richardson's collection (L.G. 44).

Small forms with strong regular costæ, resembling in ornamentation the capricorn Ammonites with which they are found. The whorls are distinctly convex, and separated by deep sutures.

Development.—The first four whorls are quite smooth, then strong slightly-curved axials (about as wide as the interspaces) appear; this type of ornamentation is characteristic of the remainder of the shell.

Fig. 17.—Zygopleura capricornu, *sp. nov. Holotype* × *8.*



This little species is characterized by the strength and regularity of its costæ and its convex whorl, which serves to distinguish it from *Zygopleura* cf. *blainvillei*.

Locality and horizon.—The holotype is a specimen from the Lower Lias (*capricornus* zone) of Stonehouse, near Stroud (Gloucestershire). Specimens which appear to be almost identical have been found by Mr. Richardson near Naunton Park Schools, Cheltenham, at a somewhat lower horizon (*valdani* zone). Other closely similar specimens were found by Dr. W. D. Lang at Black Ven, Dorset, in the *latæcosta* sub-zone, 78 feet above the Belemnite Stone (Lang Coll. No. 1030).

ZYGOPLEURA SUBRUGOSA, sp. nov. (Text-fig. 18.)

Dimensions of holotype.

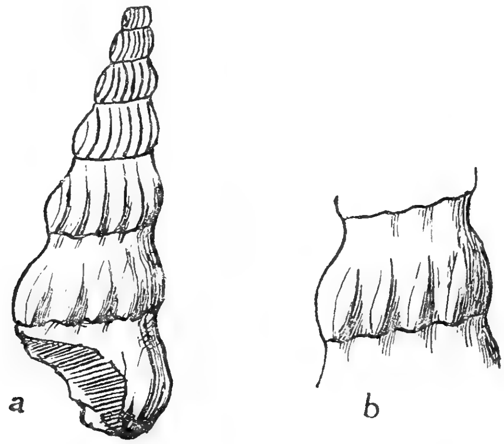
Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
16 mm.	33 per cent.	69 per cent.	18°	107°

Holotype: Collected by Mr. J. G. Hamling, F.G.S., now in the British Museum (Natural History) collection, G. 24882.

A coarsely-costate slender form, with wide concave sutures separating the later whorls.

Development.—The apical whorls are not preserved in the type-specimen, but the earliest whorls present are convex and ornamented with simple curved ribs, closely resembling *Z.* cf. *blainvillei*; on the fifth whorl present the ribs have somewhat coarsened, and this feature is more apparent on the remaining

Fig. 18.—Zygopleura subrugosa, *sp. nov.* *Holotype.*



[*a*=Complete specimen, × 3. *b*=A portion enlarged to show the moulding of the whorl and the shallow suture.]

whorls, where they become more widely separated, with a tendency to produce elongated tubercles on the anterior margin of each whorl; in one or two cases, two of the ribs appear to unite on the anterior part of the whorl. In the early whorls the sutures are normal and fairly deep; but, after three or four whorls, the sutural depression becomes wide and shallow, owing to the posterior portion of each whorl being moulded over the anterior portion of that preceding it (fig. 18 *b*).

This species has apparently been evolved from some species of *Zygopleura* comparable with *Z.* cf. *blainvillei*; but it differs from that form in the coarser ornament and imbricating whorls, in which characters it resembles *Z. subnodosa* (A. d'Orbigny) and *Z. verrucosa* (Terquem). These two last-named forms, however, are found at a much lower horizon (*angulatus* zone): it is also

interesting to note that, so far as we are aware, they have not been recorded in this country, although they are highly characteristic of the lowest zones of the Lias in parts of France.

Locality and horizon.—The holotype is a specimen from the Upper Lias of Grantham (probably *falcifer* zone), at Rudd's Brick-works.

ZYGOPLEURA cf. TÆNIATA (Deslongchamps). (Text-fig. 19.)

Cerithium tæniatum Deslongchamps (**4,** p. 200 & pl. xi, fig. 14).
Cf. *Zygopleura* (*Katosira*) *tæniata* Cossmann (**3,** pl. ix, fig. 45).

Dimensions of our specimens.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
7 mm.	29 per cent.	65 per cent.	25°	113°

Fairly slender specimens, whorls almost flat, ornamented by very fine curved axial ribs; a well-marked sub-sutural band on the posterior portion of each whorl.

Fig. 19.—Zygopleura *cf.* tæniata × *6.*

Development.—Apical whorls (about four) not preserved, the remainder of the shell is ornamented as described above.

This specimen differs from Deslongchamps's species in its smaller size, stouter form, and also in the finer ribbing; from Cossmann's species it differs in having no spirals, and also in the finer and more closely-packed axials.

Locality and horizon.—The specimen described is from the Lower Lias (*jamesoni* zone) of Toddington, Gloucestershire (L. Richardson coll. L.G. 1).

ZYGOPLEURA SEMITECTA (Tate). (Text-fig. 20, p. 332.)

Chemnitzia semitecta Tate (**24,** pl. ix, fig. 23).

Dimensions of holotype.

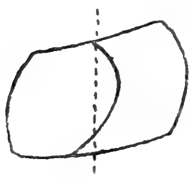
Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
14 mm.	33 per cent.	67 per cent.	23°	105°

Holotype: A specimen in the Tate Collection, Museum of Practical Geology, Jermyn Street, London, No. 16416.

Slender shell with convex whorls and a sub-sutural band; the ornamentation develops from costate to striate. The mouth is incomplete in the holotype; but in a topotype, also in the Tate Collection, the mouth is oval, with the appearance of a slight angularity on the anterior margin.

Development.—Apical whorls of shell not preserved; the earliest whorls present are convex, somewhat tumid, and ornamented by feeble ribs; the last three whorls are smooth, except for sharply curved growth-lines, and perhaps exceedingly faint spiral lines. A well-marked subsutural band is present, which may be formed by a slight tendency to mould the posterior part of the whorl on the preceding whorl.

Fig. 20.—Zygopleura semitecta *(Tate). Holotype. Diagram showing curve of growth-lines.*



This species resembles other Loxonematid species found at various horizons in the Lias, some of which have been referred to the genus *Anoptychia* by Dr. Cossmann. It differs from these species in the convex whorl and in the curve of the growth-line, and is a homœomorph of such forms as *Zygopleura hemicolpa*.

Locality and horizon.—The holotype is from the Middle Lias (*margaritatus* zone), Staithes, Yorkshire.

(B) Katosira.

Katosira is, on the whole, more abundant in the Lower Lias than *Zygopleura*, and extends into the Middle and Upper Lias. The evolution of *Katosira* may be considered to be parallel to that of *Zygopleura*, for many of the lower forms, generally speaking, have fewer axials (these may include *Chemnitzia etalensis* Piette and *Ch. collenoti* Terquem & Piette). The number of the axials is increased as the series advances, and at the same time there is a tendency for them to become more sharply curved; the spiral ornament is at first spread evenly over the whorl, but in later forms it tends to become more prominent near the sutures. In exceptional cases, the spirals are sufficiently strong to produce a suggestion of tuberculation. In some forms, the whorls embrace in the manner noticed in some species of *Zygopleura*.

Katosira cf. youngi (Tate). (Pl. XXII, fig. 5.)

Chemnitzia youngi Tate (**24**, pl. xvi, fig. 6).
Turbo youngi Simpson (**18**, p. 156).
Cf. *Cerithium quinetteum* Terquem & Piette (**26**, pl. v, fig. 4).
Cf. *Zygopleura* (*Katosira*) *chartroni* Cossmann (**3**, pl. ix, fig. 57).
Chemnitzia blainvillei Richardson *non* Münster (**17**, pl. ii, fig. 8).

Dimensions of our specimen.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
12 mm.	25 per cent.	70 per cent.	22°	108°

A slender form having convex whorls ornamented with slightly curved ribs, crossed by numerous fine spiral threads which are more pronounced near the sutures. Aperture incomplete.

Development.—The first two and a half whorls are smooth, then strong and practically straight axial ribs appear, numbering about seven to a whorl; this number increases to about twenty as the adult whorls are approached. It is difficult to discern when the spiral lines appear, but they are clearly developed before the seventh whorl. The median spirals of each whorl are much fainter than those situated nearer the posterior and anterior sutures. The early whorls are flat or only slightly convex, the later whorls are more convex, but not markedly so.

This species may be taken as a central form in a very abundant and very widely distributed group of species of *Katosira* which are found in the Charmouthian of this country. Numerous other forms differing only slightly from this may be distinguished; but it does not appear necessary at this stage to indicate new names for them. Among species named by other authors referable to this group may be mentioned *Katosira periniana* (A. d'Orbigny), *K. chartroni* Cossmann, and *K. corvalliana* (A. d'Orbigny). In this country these forms have almost always been referred to *Chemnitzia blainvillei* (Münster); but Münster's figure shows that his species is without spiral ornament.

Locality and horizon.—The specimen figured is from the Lower Lias (*jamesoni* zone) of Toddington, Winchcombe, Gloucestershire (L. Richardson coll. L.G. 28). Specimens from a somewhat lower horizon (*birchi* zone) at Pebworth (L. Richardson coll. L G. 61) differ in having stronger, straighter, and more widely-spaced ribs than *K.* cf. *youngi*, and probably represent a somewhat more primitive form; while a slender form resembling the above, but having finer and more distinctly curved ribs, found on the tunnel-heaps at Old Dalby (Leicestershire), is probably a representative from a higher zone.

Katosira transgressa, sp. nov. (Text-fig. 21, p. 334.)

Dimensions of holotype.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
10 mm.	27 per cent.	70 per cent.	20°	105°

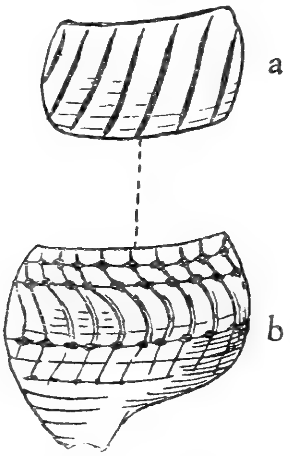
Holotype: A specimen in Mr. L. Richardson's collection, L.G. 25.

A slender form, identical with *K.* cf. *youngi* in the early whorls, but with spirals so accentuated on the last whorl as to produce minute denticulations. The specimen is slightly crushed, and the shape of the mouth is obscure.

Development.—The first two whorls are smooth, after which ribs appear. For the first eight whorls the ribs simply increase steadily in number, and the spirals are accentuated near the sutures (fig. 21 *a*) exactly as in *K.* cf. *youngi*. On the two whorls before the last the ribs become somewhat more curved, while on

the last whorl they become finer, and show a marked double curve with the development of incipient tubercles where they are crossed by the equally fine spirals (fig. 21 *b*).

Fig. 21.—Katosira transgressa, *sp. nov. Holotype enlarged.*



[*a*=about the seventh whorl; *b*=last whorl.]

This form differs from all other members of the Loxonematidæ that we have considered, in producing tiny tubercles: it has undoubtedly developed from some group resembling *K.* cf. *youngi*, and is not in any way related to the species of *Procerithium* which it comes to resemble in some degree. *K. complicata* (Tate) is a species with similar affinities.

Locality and horizon.—The holotype is a specimen from the Lower Lias (*oxynotus* zone) from the railway-cutting (G. C. R.) near Hillmorton, Rugby.

KATOSIRA CONCINNA, sp. nov. (Pl. XXII, fig. 4.)

Dimensions of holotype.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
20 mm.	25 per cent.	75 per cent.	18°	105°

Holotype: A specimen in Mr. J. W. Tutcher's collection, No. 1012.

A slender form, with convex rather tumid whorls, separated by narrow and deep sutures, the ornamentation consisting of fine, regular, and curved axial lines crossed by spirals which are prominent near the posterior suture.

Development.—The upper whorls are not clearly preserved, but apparently have straight and somewhat oblique axial ribs, which increase in number and degree of curvature; equally-spaced spirals are recognizable at a comparatively early stage, and on the penultimate whorl these are strongest near the posterior suture. On the last whorl the axials show a curve resembling that of *Katosira transversa*, and there is a very slight tendency to produce an imbricate whorl.

This form appears to be related to *K.* cf. *youngi*; but it differs in the finer ribs (about thirty to a whorl), in the greater curve of the axials, and in the shape of the whorl.

Locality and horizon.—The holotype is a specimen from the Lower Lias (*armatus* zone), Clandown Quarry, Radstock (Somerset). Somewhat similar forms were found at the same horizon at Binces' Lodge, Wilton (Somerset).

Katosira trivia (Tate). (Pl. XXII, fig. 2.)

Chemnitzia trivia Tate (**22**, p. 8).
Cf. *Turritella costifera* Piette (**13**, p. 205 & pl. x, fig. 14).
Cf. *Scalaria liassica* Quenstedt (**15**, pl. xix, fig. 12).

Dimensions of lectotype (estimated).

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
12 mm.	22 per cent.	76 per cent.	14°	109°

Lectotype: A specimen in the Museum of Practical Geology, Jermyn Street, London, No. 7990.

A very slender shell, with slightly-curved, rather oblique axial ribs, and fine spirals. The mouth is not distinct in the lectotype; but in a topotype it appears to be holostome and almost circular.

Development.—The early whorls are fairly flat, but later whorls become slightly convex, while the last whorl in the specimen figured becomes feebly ridged (convexifastigate). The apical whorls are not present, and the ornamentation described above is characteristic of the whole shell.

On account of its slender form and the obliquity of its axial ribs, *K. trivia* is not likely to be confused with any other species that has been found in England. Some other forms of *Katosira* with oblique ribs have been described by Piette from the lowest zones of the Lower Lias in France; one of these is *K. costifera* (Piette), which is somewhat stouter than our specimens. Catagenetic descendants from these obliquely ribbed species seem to include *Turritella intermedia* Terquem & Piette, and *T. semiornata* Terquem & Piette.

Locality and horizon.—The lectotype is a specimen from the Lower Lias of Bridgend; as the lowest zones only of the Lower Lias are present here, this species is not later than the *semicostatus* zone, and is almost certainly from the *bucklandi* zone. The comparable species found in France appear likewise to be characteristic of a low horizon.

Katosira (Rigauxia) noguesi (Dumortier). (Pl. XXII, fig. 3.)

Chemnitzia noguesi Dumortier (**5**, pt. 2, 1867, p. 183 & pl. xlv, figs. 4-5).
Cf. *Turritella undulata* Quenstedt (**15**, pl. xix, fig. 14).

Dimensions of specimen figured by us (estimated).

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
30 mm.	14 per cent.	85 per cent.	10°	110°

Rather large but very slender shells ornamented with stout ribs, which do not quite extend from suture to suture, and numerous regular spirals; the sutural region is wide and shallow, the whorls imbricating.

Development.—This species shows in the convex early whorls widely-spaced strong ribs crossed by spirals; but in the later whorls the axials have become low oblique folds crossed by regular

spirals which are somewhat more pronounced in the wide sutural region. There is a tendency also in these later whorls for the posterior portion to be moulded on the preceding whorl with the formation of a concave sutural area. (Compare fig. 18 *b*, p. 330.)

This species may be regarded to some extent as constituting a morphic equivalent of *Z. subrugosa*; doubtless a similar tendency towards the shallowing of the sutural region and the embracing of the whorls is to be found in both divisions of the Loxonematidæ.

Locality and horizon.—Our specimen was found in the Lower Lias (*armatus* zone) of Binces' Lodge, Wilton (Somerset), and is in Mr. J. W. Tutcher's collection, No. 1038. A somewhat similar specimen (Pl. XXII, fig. 7), in which the ribs of the later whorls are more curved, was found by Mr. Tutcher at the same horizon at Clandown Quarry, Radstock (J. W. Tutcher coll., No. 1008).

VI. Other Liassic Turriculate Gastropods.

Family MATHILDIIDÆ Cossmann.

Promathildia Andreæ.

This genus includes a number of species showing considerable differences in ornamentation and shape, which resemble one another in having an elongated shell, a holostome aperture, frequently angular, and heterostrophic embryonic whorls.

In most of the species spirals appear before axials, and are more important than the axials in the ornamentation of adult whorls; several species tend to be strongly carinate. Examples of the genus are not common in the Liassic rocks of this country, for which reason it is not proposed in this paper to suggest any grouping of the species.

Promathildia tenuicostata (Portlock). (Pl. XXII, fig. 6.)

Cerithium tenuicostatum Portlock (**14**, p. 124).
C. tenuicostatum Tate (**21**, p. 15).

Dimensions of a typical specimen.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
5 mm.	30 per cent.	60 per cent.	20°	115°

Small slender forms, with holostomatous aperture and heterostrophic embryonic whorls; spiral and axial ornamentation fine, with the exception of three anterior spirals which are much stronger.

Development.—After the smooth heterostrophic embryonic whorls, the first ornamentation to appear is a single spiral occupying an antero-median position; very fine curved axials soon make

their appearance, and by the fourth whorl from the apex the ornamentation typical of the species has been established: that is, three strong spirals on the lower half of the whorl, and four or five spiral threads on the upper half, crossed by very fine curved axials.

Locality and horizon.—The specimens described are recorded from the Lower Lias of Ballintoy, and are in the Tate Collection, Museum of Practical Geology, Jermyn Street, London, No. 7965.

Promathildia ibex (Tate). (Text-fig. 22.)

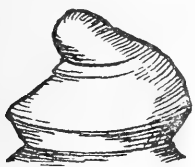
Cerithium ibex Tate (**17**, pl. ii, fig. 9; also **20**, p. 405 & pl. xxvi, fig. 18).
C. ibex Richardson (**16**, pl. xiv, fig. 3).

Dimensions of a typical specimen.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
12 mm.	32 per cent.	75 per cent.	20°	113°

Slender shells, with slightly heterostrophic embryonic whorls; the succeeding whorls are angular and quite smooth, except for two spiral bands, one of which forms the anterior carina, while the other may be regarded as a sub-sutural band just beneath the posterior suture of the whorl. Our specimens, though smaller, conform with Tate's description in every respect, except that in all cases the mouth is circular without any suggestion of a canal.

Fig. 22.—Promathildia ibex. *Embryonic whorls × 10 (approximately) showing heterostrophic character.*



Locality and horizon.—Our specimen is from the Lower Lias (*valdani* zone) of Leckhampton, Cheltenham (L. Richardson coll., L.G. 3 a). Another specimen from the same horizon was found at Hucclecote, near Gloucester (L. Richardson coll., L.G. 4). Very near this horizon are found other *ibex*-like specimens practically identical with the above, but showing slight variations in detail; for instance, in a specimen from the *jamesoni* zone of Toddington, near Winchcombe (L. Richardson coll., L.G. 22), there is an additional sub-sutural band, almost touching the first-formed. In other forms several additional spirals are added in the later whorls, as, for instance, in a specimen from the Lower Lias of Bengeworth, Worcestershire (Natural History Museum, G. 10739).

Promathildia ligaturalis (Tate). (Text-fig. 23, p. 338.)

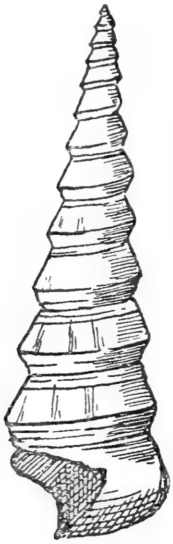
Cerithium ligaturale Tate (**22**, p. 7).

Dimensions of holotype.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
14·5 mm.	28 per cent.	79 per cent.	17°	112°

Holotype: A specimen in the Museum of Practical Geology, Jermyn Street, London, No. 7961.

Fig. 23.—Promathildia ligaturalis. *Holotype* × 4.



A slender form, with angular whorls ornamented by spirals and widely-spaced axial folds.

The development cannot be made out; the ornamentation characteristic of the shell consists of two spirals, the highest of which forms a carina on the anterior third of each whorl, and a double sub-sutural band near the posterior suture. The space between the spirals is smooth, except for a slight wrinkling caused by distant axial folds.

This species, from its resemblance in form and ornamentation to *P. ibex*, is referred to *Promathildia*, although the embryonic whorls have not been seen.

Locality and horizon.—The holotype is a specimen from the Lower Lias of Redmile (Lincolnshire).

PROMATHILDIA TRIGEMMATA (Wilson).

Cerithium trigemmatum Wilson (**27**, pl. v, figs. 10 & 10*a*).

Dimensions of our specimen.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
4 mm.	37 per cent.	75 per cent.	24°	99°

Small slender shells, with more or less angular whorls, ornamented by three rows of tubercles, the lowest set forming a well-marked anterior carina. The outline of the oral region in our specimen shows no indication of the presence of a canal, and we infer that the mouth is holostome.

Development.—The embryonic whorls are smooth and heterostrophic. The first ornament to appear, so far as can be made out, consists of two spiral bands, the stronger of the two occupying an anterior position; almost immediately axial ornament appears, and tubercles are produced at the points of intersection. By the fifth whorl a faint third spiral is intercalated, and the remainder of the shell is ornamented by three rows of equally-spaced rounded tubercles of unequal size, the anterior set of which forms a well-marked carina. An extra spiral is added on the last whorl beneath the carina.

As has been already noted, our specimen is holostomatous, but Wilson described the aperture of his specimen as having a faint

indication of the commencement of an anterior canal. This would suggest that it is a member of the Procerithidæ; we originally thought that such was the case, for the general style of ornamentation and the shape of the whorl lead one to suspect that it is near the *Procerithium-ogerieni* stock, and arose as a distinct species by the accentuation of the anterior set of tubercles. However, owing to the presence of heterostrophic embryonic whorls and the presumed absence of a canal, we consider it advisable to put this species, provisionally at least, among the Mathildiidæ.

This grouping together of species with heterostrophic embryonic whorls assumes that the latter feature is of great importance in classification. There is considerable variation in the heterostrophic embryonic whorls in different examples of the same species; but in such groups we have found no examples with homœostrophic embryos, and this character appears to be of greater value in classification than we had originally been disposed to admit.[1]

Locality and horizon.—The holotype was found in the Lower Lias, on the tunnel-heaps at Old Dalby (Leicestershire). The specimens described here (J. W. Tutcher coll., No. 1002), and other specimens preserved at University College, Nottingham, were found at the same locality.

Family CŒLOSTYLINIDÆ Cossmann.

Bourguetia Cossmann.

Bourguetia deshayesea (Terquem).

Turritella deshayesea Terquem (**25**, pl. xiv, fig. 7).
T. deshayesea Terquem & Piette (**26**, p. 37).
Bourguetia deshayesea Cossmann (**2**, vol. viii, 1909, p. 71).

Dimensions of our specimen.

Length.	*Breadth.*	*Length of spire.*	*Spiral angle.*	*Sutural angle.*
56 mm.	35 per cent.	65 per cent.	24°	106°

A very large shell, having tumid convex whorls separated by deep sutures, ornamented entirely by numerous transcrescentic striæ.

Development.—The apical whorls are not preserved, and consequently the early development is not seen; the nine whorls present are all similar in shape and ornamentation. The oral margin is not preserved.

Locality and horizon.—The specimen described is from the Lower Lias (*bucklandi* zone) of Redcar, Yorkshire. (In the Tate Collection, Museum of Practical Geology, Jermyn Street, London, No. 8467.)

[1] The presence or absence of heterostrophic embryonic whorls is used in classifying several groups of recent gastropods.

VII. Geological Distribution.

The present investigation was undertaken, chiefly in order to determine the value of Gastropods in the correlation of Mesozoic rocks. In the zoning of Jurassic rocks the Ammonites have hitherto proved most useful; but it is well known that in some divisions of the Jurassic rocks ammonites are rare, and in such cases greater attention must necessarily be paid to other fossils. Naturally, those organisms are most useful in correlation that have evolved rapidly in some definite direction, and it will therefore be convenient to consider briefly the evolution of the two most important families with which we have been concerned: namely, the Procerithidæ and the Loxonematidæ.

(1) Procerithidæ.

The Procerithidæ are very common in the Liassic rocks of this country, the genus *Procerithium* being particularly abundant. In England other genera such as *Cryptaulax*, *Cerithinella*, and *Paracerithium* do not appear to be by any means common. *Procerithium* is found somewhat sparingly in Hettangian rocks, more commonly in the Sinemurian, and apparently becomes most abundant in the Charmouthian. At some horizons in the Middle and Upper Lias, notably in the *acutum* zone of Leicester, *Procerithium* again becomes common. In the lowest zones of the Lower Lias the predominant species of *Procerithium* have somewhat flat whorls, ornamented by a network based on three spirals, and these species may be considered as constituting the central stock of *Procerithium* in the Lias; one of the most typical species is *P. ogerieni*. From them evolved numerous offshoots, some by the addition of spirals, others by the accentuation of a spiral forming a carina, others by differentiation of the ornamentation. This central stock presumably existed with little modification throughout the Liassic Period, and gave rise to species of the *Procerithium-muricatum* type, which are the dominant forms in the Inferior Oolite.[1] This type resembles very closely the *P. ogerieni*-type of the Lias, of which it is probably a descendant; but it has progressed in size, in the development of a canal, and in the addition of a fourth spiral.

We may, therefore, note that, while the main stock of *Procerithium* apparently progressed slowly throughout Jurassic times, yet there were numerous species of *Procerithium* that may have been offshoots from the central stock, in which evolution was much more rapid.

(2) Loxonematidæ.

The Loxonematidæ are chiefly represented in the British Lias by two main divisions, *Zygopleura* and *Katosira*; they are extremely common in the Lower Lias, but are rare in the Middle

[1] **9**, p. 145.

and Upper Lias. In each of these groups evolution progresses in a similar direction: the earlier forms appear to be rather sparsely costate, while generally the later forms are more finely ribbed, and the ribs are more distinctly curved (fig. 14, p. 327). These changes take place somewhat rapidly, and species become distinct by the curve of the ribs and by the degree of prominence and the position of spiral lines. On the whole, it is more difficult to identify species among the Loxonematidæ than among the Procerithidæ, since fewer characters are available.

It will appear from the facts set forth above that the evolution of these gastropods generally proceeded much more slowly than the evolution of many of the Ammonite families, and therefore correlation by gastropods will be much more difficult than correlation by ammonites. It must be remembered, however, that some series of the Procerithidæ evolved fairly rapidly, and that some species of such series have been found to characterize definite horizons; it is extremely probable that, if care be taken in identifying the species, such forms would prove extremely useful in correlation.

On the other hand, there will be considerable difficulty in identifying many of these specialized gastropods; as a result of evolution along parallel or nearly parallel lines homœomorphs are of frequent occurrence, and, since these have not always been developed simultaneously, careful discrimination and the use of ontogenetic evidence are necessary to distinguish species which may be superficially alike, but may be widely separated in time and affinity.

Further, the long vertical range of these groups of Gastropoda makes their use in stratigraphical work extremely difficult, because it is impossible in many cases, even approximately, to date a specimen without accurate naming, while it is, of course, possible roughly to determine a zone by means of an ammonite without expert knowledge or careful examination. Indeed, it seems that the Gastropod families that we have been discussing, the Procerithidæ and Loxonematidæ, are to be compared rather with such slowly-evolving Ammonite families as the Lytoceratidæ and Phylloceratidæ, than with the Amaltheidæ or the Arietidæ.

In conclusion, we wish to thank those who have helped by lending or giving specimens, or allowing access to collections in their charge, namely: Mr. J. G. Hamling, Dr. F. L. Kitchin, Dr. W. D. Lang, Mr. L. Richardson, Prof. H. H. Swinnerton, and Mr. J. W. Tutcher. We are also indebted to Mr. S. S. Buckman and Dr. A. E. M. Cossmann for several suggestions. One of us (A.E.T.) wishes to acknowledge a grant from the Royal Society Committee which has enabled him to collect extensively in Somerset.

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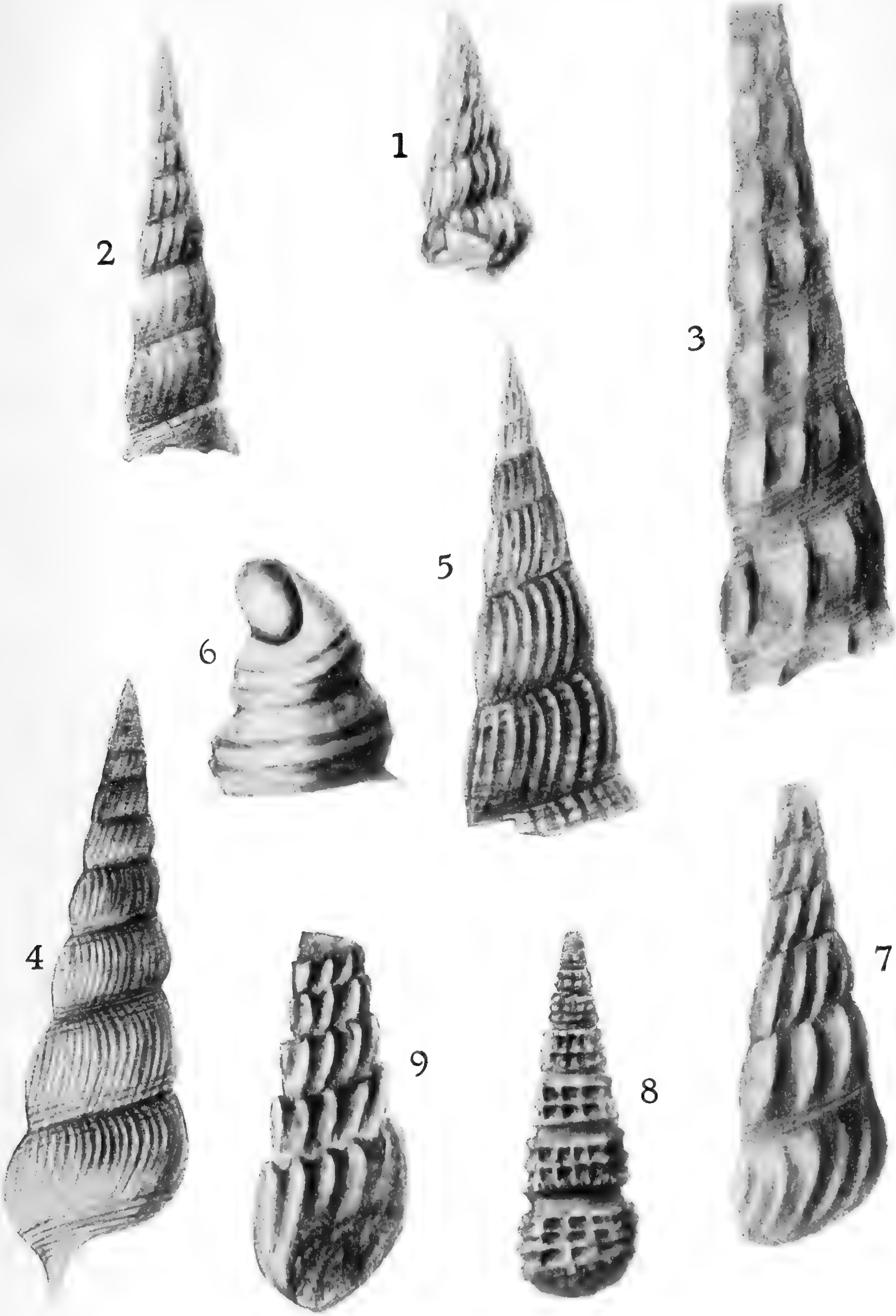

A. I. McD. del

LIASSIC GASTROPODS.

EXPLANATION OF PLATE XXII.

Fig. 1. *Zygopleura* cf. *blainvillei* (Münster). × 4. From the Lower Lias (*armatus* zone), the brickworks, Folly Lane, Cheltenham. (L. Richardson Coll., L.G. 8.) See p. 326.

2. *Katosira trivia* (Tate). Lectotype × 5. From the Lower Lias, Bridgend, Glamorgan. (Tate Coll., Museum of Practical Geology, No. 7990.) See p. 335.

3. *Katosira* (*Rigauxia*) *noguesi* (Dumortier). × 4. From the Lower Lias (*armatus* zone), Bince's Lodge, Wilton, Somerset. (J. W. Tutcher Coll., No. 1038.) See p. 335.

4. *Katosira concinna*, sp. nov. Holotype × 4. From the Lower Lias (*armatus* zone), Clandown Quarry, Radstock, Somerset. (J. W. Tutcher Coll., No. 1012.) See p. 334.

5. *Katosira* cf. *youngi* (Tate). × 5. From the Lower Lias (*jamesoni* zone) of the railway-cutting, Toddington, near Winchcombe, Gloucestershire. (L. Richardson Coll., L.G. 28.) See p. 332.

6. *Promathildia tenuicostata* (Portlock). Embryonic whorls × 10. From the Lower Lias of Ballintoy. (Tate Coll., Museum of Practical Geology, No. 7965.) See p. 336.

7. *Katosira* (*Rigauxia*) sp. × 6. From the Lower Lias (*armatus* zone), Clandown Quarry, Radstock, Somerset. (J. W. Tutcher Coll., No. 1008.) See p. 336.

8. *Procerithium ogerieni* (Dumortier). × 8. From the Lower Lias of the tunnel-heaps, Old Dalby, Leicestershire. (Geological Collection, University College, Nottingham.) See p. 311.

9. *Paracerithium* sp. × 2·5. From the Oolite Bed, *falcifer* zone, Upper Lias, Grantham, Lincolnshire. See p. 324.

Discussion.

Dr. F. A. Bather complimented the Authors on the great interest of their work, and Dr. Trueman on his lucid presentation. He would be glad to hear any explanation of the changes in ornament. He assumed that the axial ridges were intensifications of growth-lines, and that the spiral ridges were connected with differential tension of the mantle. But were these changes due to internal factors alone, or were they adaptations to some external factors? What could those factors be?

Dr. A. M. Davies congratulated the Authors on their investigation of a neglected group, and remarked on the general rarity of fossil gastropods preserved perfect from protoconch to mouth-border. As to the two sets of ornament-lines, he suggested that, while the axial or growth-lines were the expression of a time-rhythm in the activity of the mantle-edge, the spiral lines (like the radiating lines of lamellibranchs) were the expression of an unequal local distribution of that activity, amounting in some cases to a 'space-rhythm.'

Mr. W. P. D. Stebbing expressed the opinion that the development of ribs and ridges on the shells of gastropods was independent of the strength of the shell, and that colour-markings developed in an analogous manner.

Miss McDonald emphasized the value of ontogenetic characters

in constructing a classification of Gastropoda, and pointed out how these have been used by Prof. Grabau in his studies of Tertiary groups. The order of appearance of the spiral and axial ornament will similarly prove useful in the study of the Liassic gastropods which are referred to *Trochus* and *Pleurotomaria*.

Dr. TRUEMAN thanked Dr. Bather and Dr. Davies for their kind remarks. He agreed with the suggestions put forward by the latter speaker, that the axial ornament generally coincides with the growth-lines, and that the ribs arise by a rhythmic strengthening of such lines. He pointed out that smooth shells are generally thinner than the more ornamented species. The Authors had been fortunate in securing a great number of small gastropods with protoconchs complete, from the Liassic clays; but, unfortunately, specimens collected in limestones are not, as a rule, sufficiently well preserved to show details of ontogeny.

GENERAL INDEX

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